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Meet the editor

Vedran Kordic is the founder and Board member of IntechOpen. After obtaining his Master's degree in Mechanical Engineering he continued his education at the Vienna University of Technology where he obtained his PhD degree in 2004. He worked as a researcher at the Automation and Control Institute, Faculty of Electrical Engineering, Vienna University of Technology until 2008. His studies in robotics lead him not only to a PhD degree but also inspired him to co-found and build the International Journal of Advanced Robotic Systems - world's first Open Access journal in the field of robotics. Vedran's background and experience remain crucial for the company's development as he is continuously engaged with overseeing the IT department.

Preface

Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization.

An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money.

From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle.

The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

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Supply Chain Collaboration

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1. Introduction

In the past, research in operations management focused on single-firm analysis. Its goal was to provide managers in practice with suitable tools to improve the performance of their firm by calculating optimal inventory quantities, among others. Nowadays, business decisions are dominated by the globalization of markets and increased competition among firms. Further, more and more products reach the customer through supply chains that are composed of independent firms. Following these trends, research in operations management has shifted its focus from single-firm analysis to multi-firm analysis, in particular to improving the efficiency and performance of supply chains under decentralized control. The main characteristics of such chains are that the firms in the chain are independent actors who try to optimize their individual objectives, and that the decisions taken by a firm do also affect the performance of the other parties in the supply chain. These interactions among firms' decisions ask for alignment and coordination of actions. Therefore, game theory, the study of situations of cooperation or conflict among heterogenous actors, is very well suited to deal with these interactions. This has been recognized by researchers in the field, since there are an ever increasing number of papers that applies tools, methods and models from game theory to supply chain problems.
The field of game theory may be divided roughly in two parts, namely non-cooperative game theory and cooperative game theory. Models in non-cooperative game theory assume that each player in the game (e.g. a firm in a supply chain) optimizes its own objective and does not care for the effect of its decisions on others. The focus is on finding optimal strategies for each player. Binding agreements among the players are not allowed. One of the main concerns when applying non-cooperative game theory to supply chains is whether some proposed coordination mechanism, or strategy, coordinates the supply chain, that is, maximizes the total joint profit of the firms in the supply chain. In contrast, cooperative game theory assumes that players can make binding agreements. Here the focus is on which coalition of players will form and which allocation of the joint worth will be used. One of the main questions when applying cooperative game theory to supply chains is whether cooperation is stable, that is, whether there exists an allocation of the joint profit among all the parties in the supply chain such that no group of them can do better on its own. Up to date, many researchers use non-cooperative game theory to analyse supply chain problems.

This work surveys applications of cooperative game theory to supply chain management. The supply chains under consideration are so-called divergent distribution networks, which consist of a single supplier and a finite number of retailers. In particular, we focus on two important aspects of supply chain collaboration. First, we focus on *inventory centralization*, also called inventory pooling.

Retailers may collaborate to benefit from the centralization of their inventories. Such collaboration may lead to reduced storage costs, larger ordering power, or lower risks, for example. Models from cooperative game theory may be used to find stable allocations of the joint costs. Such allocations are important to obtain and maintain the collaboration among the retailers. There is a steady stream of papers on this subject and these are reviewed here.

Second, we consider *retailer-supplier relationships*. Besides collaboration among retailers only, a further gain in efficiency may be obtained by collaboration between the supplier and the retailers. Also here, the question is how to reduce the joint costs. Cooperative game theory may be used to find stable allocations of the joint costs. Although a natural field to research, these problems are hardly studied by means of cooperative game theory. We review the few papers in the literature and indicate possibilities for future research.

We wish to point out that there are several other areas of cooperative games that lend themselves nicely to applications in supply chains, but that we do not review. One may think of bargaining models for negotiations among supply chain partners, network models to study multi-echelon supply chains, or coalition formation among supply chain partners, to name some themes. For bargaining models and coalition formation we refer to the review by Nagarajan & Sošić (2006), and for theoretical issues and a framework for more general supply chain networks we refer to Slikker & Van den Nouweland (2001).

This work is organized as follows. In section 2 we introduce some basic concepts of cooperative game theory. This helps understand how the collaboration among several agents is modelled. With this understanding, some well known results from the literature on cooperative game theory are surveyed. Thereafter we review applications of cooperative game theory to inventory centralization (section 3). Section 4 reviews and discusses retailer-supplier relationships. Finally, section 5 concludes and highlights areas for future research.

2. Cooperative game theory

Game theory provides tools, methods and models to investigate supply chain collaboration, coordination and competition. The game theory literature can roughly be divided into cooperative and non-cooperative game theory. There are some differences between analyses using non-cooperative game theory and those using cooperative game theory. When applying non-cooperative game theory, it is assumed that each player acts individually according to its objective, and usually the mechanisms to get it are investigated. One of the main points of concern is whether the proposed mechanism provides a solution that maximizes the total supply chain profit under Nash equilibrium.

In contrast, cooperative game theory does not investigate the individual behaviour of the players explicitly and assume that once the players form a coalition, the coordination between them is achieved one way or another (i.e., either by making binding agreements and commitments or by a suitable coordination mechanism). Although cooperative games abstract from the details of mechanism that lead to cooperation, they are very powerful to investigate the problem of allocation of worth in detail. Here, the main question is whether the cooperation is stable, i.e. there are stable allocations of the total worth or cost among the players such that no group of them would like to leave the consortium. Cooperative game theory offers the concept of the core (Gillies, 1953) as a direct answer to that question. Non-emptiness of the core means that there exists at least one stable allocation of the total worth such that no group of players has an incentive to leave. In this chapter, we concentrate ourselves mainly on the analysis of coordination induced by cooperation (collaboration). In this approach cooperative game theory will be instrumental.

Roughly speaking, a transferable utility game (henceforth TU game) is a pair consisting of a finite set of players and a characteristic function, which measures the worth (benefit or cost) of every coalition of players, i.e. subset of the finite initial set (grand coalition), through a real valued mapping. The sub-game related to a particular coalition is the restriction of the mapping to the sub-coalitions of this coalition. A worth-sharing vector will be a real vector with as many components as the number of players in the game. The core of the TU game consists of those efficient worth-sharing vectors which allocate the worth (cost) of the grand coalition in such a way that every other coalition receives at least (or pays at most) its worth, given by the characteristic function. In the following, worth-sharing vectors belonging to the core will be called core-allocations. A TU game has a non-empty core if and only if it is balanced (see Bondareva 1963 or Shapley 1967). It is a totally balanced game if the core of every subgame is non-empty. Totally balanced games were introduced by Shapley and Shubik in the study of market games (see Shapley & Shubik, 1969).

A population monotonic allocation scheme (see Sprumont 1990), or pmas, for a TU game guarantees that once a coalition has decided upon an allocation of its worth, no player will ever be tempted to induce the formation of a smaller coalition by using his bargaining skills or by any others means. It is a collection of worth-sharing vectors for every sub-game satisfying efficiency property and requiring that the worth to every player increases (or decreases) as the coalition to which it belongs grows larger. Note that the set of worth-sharing vectors that can be reached through a pmas can be seen as a refinement of the core. Every TU game with pmas is totally balanced.

A game is said to be super-additive (or sub-additive) if it is always beneficial for two disjoint coalitions to cooperate and form a larger coalition. Balanced TU games might not be super-additive (sub-additive), but they always satisfy super-additive (sub-additive) inequalities involving the grand coalition. However, totally balanced TU games are super-additive (sub-additive). A well-known class of balanced and super-additive (sub-additive) games is the class of convex (concave) games. A TU game is said to be convex if the incentives for joining a coalition increase as the coalition grows, so that one might expect a "snowballing" effect when the game is played cooperatively (Shapley, 1971).

Another class of balanced and super-additive (sub-additive) games is the class of permutationally convex (concave) games (Granot & Huberman, 1982). A game is permutationally convex (concave) if and only if there exists an ordering of the players for the grand coalition such that the game is permutationally convex (concave) with respect to this ordering. Granot & Huberman (1982) showed that every permutationally concave TU game is balanced.

A worth allocation rule for TU games, is a map which assigns to every TU game a worth-sharing vector. One example of such a worth allocation rule is the proportional rule. This proportional division mechanism allocates the worth of the grand coalition in a proportional way according to a fixed proportionality factor (e.g., the individual worth for each player).

3. Inventory centralization

Generally speaking, shops or retailers trade various types of goods, and to keep their service to their customers at a high level they aim at meeting the demand for all goods on time. To attain this goal, retailers may keep inventories in a private warehouse. These inventories bring costs along with them. To keep these costs low, a good management of the inventories is needed. The management of inventory, or inventory management, started at the beginning of this century when manufacturing industries and engineering grew rapidly. To the best of our knowledge, a starting paper on mathematical models of inventory management was Harris (1913). Since then, many books on this subject have been published. For example, Hadley & Whitin (1963), Hax & Candea (1984), Tersine (1994), and Zipkin (2000). Most often, the objective of inventory management is to minimize the average cost per time unit (in the long run) incurred by the inventory system, while guaranteeing a pre-specified minimal level of service.

In this section, we review the literature and study the applications of cooperative game theory to inventory centralization in supply chains. The supply chains that we focus on along this work are divergent distribution networks that consist of a supplier and a finite number of retailers. The main motivation behind using a cooperative game is that it allows us to establish a framework to examine the effect of coordinated ordering/holding by the retailers, which generates some joint worth (benefit or cost), using cooperative game theory solutions across several structurally different inventory centralization models. The main focus of concern is how to allocate the worth among the retailers. In doing so, we try to find stable allocations of worth, which is important for the existence and stability of the cooperation.

In this study, we primarily focus on coordination in continuous review inventory situations. In this framework, the class of inventory games arises when considering the possibility of joint ordering, and holding, in n-person Economic Order Quantity (or Economic Production Quantity) inventory situations in order to reduce the total inventory costs. The underlying Operation Research problems are the well-known EOQ (EPQ) situations, which were already introduced by Harris (1915). In these continuous time models with infinite horizon it is assumed that a single retailer faces a constant demand rate with the objective of minimizing its inventory costs.

A natural extension of this model is to consider now coordination in the classical Wagner-Whitin problem (see Wagner & Whitin 1958). It can be seen as a periodic version of the above model with finite horizon and time varying demand. Here new types of production/ inventory games arise when a collection of retailers tries to minimize their total inventory costs by joint ordering/holding. All of them make up the class of dynamic inventory games.

Finally, we pay attention to coordination in a multiple newsvendor setting. The newsvendor model is first introduced by Arrow et al. (1951) and it was originated by the story of a newsboy who faces random demand and has to decide everyday how many newspapers to buy to maximize his expected profit. The newsvendor models are often used to support decision making in several situations with highly perishable products or products with short life cycle. The focus of this study is the inventory centralization in newsvendor environments. Newsvendor games arise when a finite number of stores (newsvendors) respond to a periodic random demand (of newspapers) by ordering jointly at the start of every period. Their main objective is to minimize the resulting expected cost.

This section is organized as follows. We first provide an overview of inventory games in subsection 3.1. Thereafter the class of dynamic inventory games arises as a natural extension of the former (subsection 3.2). Finally, newsvendor games are analyzed and surveyed in subsection 3.3.

3.1 Inventory games

Inventory situations, introduced in Meca et al. (2004), study how a collective of retailers can reduce its joint inventory costs by means of cooperative behaviour. Depending on the information revealed by each individual retailer, the authors analyze two related cooperative games: inventory cost games and holding cost games. For both classes of games, they focus on proportional division mechanisms to share the joint cost.

In an inventory cost game, a group of retailers dealing with the ordering and holding of a certain commodity (every individual agent's problem being an EOQ problem), decide to cooperate and jointly make their orders. To coordinate the ordering policy of the retailers, some revelation of information is needed: the amount of revealed information between the retailers is kept as low as possible since they may be competitors on the consumer market. However, in a holding cost game coordination with regard to holding cost is considered. In this case full disclosure of information is needed. These kinds of cooperation are not unusual in the economic world: for instance, pharmacies usually form groups that order and share storage space. Meca et al. (2004) introduce and characterize the SOC-rule (Share the Ordering Costs) as a core-allocation for inventory cost games, and Meca et al. (2003) revisit inventory cost games and the SOC-rule. There it is shown that the wider class of n-person EPQ inventory situations with shortages leads to exactly the same class of cost games. Moreover, an alternative characterization of the SOC-rule is provided there. Mosquera et al. (2007) introduce the property of immunity to coalition manipulation and demonstrate that the SOC-rule is the unique solution for inventory cost games that satisfies this property. In addition, Meca et al. (2004) shows that holding cost games are permutationally concave. Moreover, the demand proportional rule leads to a core-allocation of the corresponding game that can even be sustained as a pmas.

Later, Meca (2007) completes the study of holding cost games. A more general class of inventory games, inspired by the aforementioned ones, is presented in that paper, namely the so-called generalized holding cost games. It is shown that generalized holding cost games and all their subgames are permutationally concave; hence generalized holding cost games are totally balanced. Thereafter the author focuses on the study of a core-allocation family which is called N-rational solution family. It is shown that a particular relation of inclusion exists between the above family and the core. Finally a new proportional rule called minimum square proportional rule is studied, which is an N-rational solution.

On the other hand, Toledo (2002) analyzes the class of inventory games that arises from inventory problems with special sale prices. A collective of retailers trying to minimize its joint inventory cost by means of cooperation may receive a special discount on set-up cost just in ordering. Reasons for such a price reduction range from competitive price wars to attempted inventory reduction by the supplier. Each retailer has its own set-up cost which is invariant to the order size. Meca et al. (2007) assume that when an order is being placed, it is revealed that the supplier makes a special offer for the next order. Notice that the above condition makes sense from an economic point of view since if one retailer is a very good client then the supplier himself would benefit by giving the client preferential treatment.

Cooperation among retailers is given by sharing the order process and warehouse facilities: retailers in a coalition make their orders jointly and store their inventory in the cheapest warehouse. This cooperative situation generates the class of inventory games with non discriminatory temporary discounts. This new class of games motivates the study of a more general class of TU games, namely p-additive games. It contains the class of inventory games with non discriminatory temporary discounts as well as the class of inventory cost games (Meca et al. 2003). Meca et al. (2007) shows that p-additive games are totally balanced. They also focus on studying the character concave or convex and monotone of p-additive games. In addition, the modified SOC-rule is proposed as a solution for p-additive games. This solution is suitable for p-additive games since it is a core-allocation, which can be reached through a pmas. Moreover, two characterizations of the modified SOC-rule are provided.

Tijs et al. (2005) study a situation where one agent has an amount of storage space available and the other agents have some goods, part of which can be stored generating benefits. The problem of sharing the benefits produced by full cooperation between agents is tackled in this paper, by introducing a related cooperative game. This game turns out to be a big boss game with interesting theoretical properties. A solution concept, relying on optimal storage plans and associated holding prices, is also introduced, and its relationship with the core of the above holding game is explored in detail. The family of monotonic decreasing bijective mappings, defined on the set of non-negative real numbers, plays an important role in their approach.

An interesting addition to Inventory Games (as its authors claim) is the paper Hartman & Dror (2007). Its point of departure is the inventory cost game described in Meca et al. (2004). The former paper examines a collaborative procurement for the EOQ model with multiple items (items are considered as good types or types of commodities). The authors consider an inventory model with joint ordering in which the cost of ordering an item has two separable components- a fixed cost independent of the item type, and an item specific cost. They address two questions: what items should be ordered together, and how to share the ordering costs among the different items. Then they prove that consolidation of all the items is cheaper if there are fair cost allocations (the core of the game is non-empty). It happens when the portion of the ordering cost common to all items is not too small. They further show how sensitive the non-empty core is to adjustments in the cost parameters.

Finally, another appealing contribution to Inventory Games is the joint replenishment games with a submodular joint setup cost function proposed by Zhang (2007). The author shows that this game is balanced. He also shows that a special case of this game is concave, which generalizes one of the main results of Anily & Haviv (2006).

3.2 Dynamic inventory games

As mentioned before, one of the main objectives of the retailers is cost reduction. In order to achieve this goal, groups of retailers tend to form coalitions to decrease operation costs by making dynamic decisions throughout a finite planning horizon. In tactical planning of enterprises that produce indivisible goods, operation costs mainly consist of production, inventory-holding, and backlogging costs. These coalitions should induce individual and collective cost reductions; thus, stability is achieved in the process of enterprise cooperation.

In our framework a coalition allows each of its members to have access to the technologies owned by the other members of the coalition. Thus, members of a coalition can use the lowest-cost technology of the retailers in the coalition. Planning is done throughout a finite time horizon; at the beginning of each period, the costs to the members of a coalition, which depend on the best technology at that point, may change.

The model that represents such a situation is the dynamic, discrete, finite planning horizon production-inventory problem with backlogging. The objective of any group of retailers is to satisfy the demand for indivisible goods in each period at a minimum cost. This is a well-known combinatorial optimization problem for which the algorithm by Wagner & Whitin provides optimal solutions by dynamic programming techniques. The optimal solutions of this problem lead to the best production-inventory policy for the group of retailers. These policies generate an optimal operation cost for the entire group. The question is what portion of this cost is to be supported by each retailer. Cooperative game theory provides the natural tools for answering this question.

The study of cooperative combinatorial optimization games, which are defined through characteristic functions given as optimal values of combinatorial optimization problems, is a fruitful topic (see for instance Shapley & Shubik, 1972, Dubey & Shapley, 1984, Granot, 1986, Tamir, 1992, Deng et al. 1999 and 2000, and Faigle & Kern, 2000). There are characterizations of the total balancedness of several classes of these games. Inventory games and combinatorial optimization games are, up to date, disjoint classes of games. While in the former class there is always an explicit form for the characteristic function of each game, the characteristic function of the games in the latter class it is defined implicitly as the optimal value of an optimization problem in integer variables.

Guardiola et al. (2007a) introduce a class of production-inventory games that combines the characteristics of inventory and combinatorial optimization games: this class models cooperation on production and storage of indivisible goods and its characteristic function is defined implicitly as the optimal value of a combinatorial optimization problem. It turns out to be a new class of totally balanced combinatorial optimization games.

Further, the authors consider a group of agents, each one facing a PI-problem, that decide to cooperate to reduce costs, and then a production-inventory situation (henceforth, PI-situation) arises. Then, for each PI-situation, the corresponding cooperative game structure, namely production-inventory game (henceforth, PI-game), is defined. The main results are total balancedness and an explicit form for the characteristic function. The study of PI-games is completed by showing that the Owen set of a PI-situation (the set of allocations that are achievable through dual solutions, see Owen 1975 and Gellekom et al. 2000) shrinks to a singleton: the Owen point. This fact motivates the name Owen point rather than Owen set within this class of games. Guardiola et al. (2007a) propose the Owen point as a core-allocation for a PI-game which is easy to calculate and satisfies good properties. Its explicit form is also provided, and moreover, it is proved that the Owen point can be reached through a pmas. Hence, every PI-game is a non-negative cost game allowing for pmases (henceforth, PMAS-game). In addition, a necessary and sufficient condition for the core of a PI-game to be a singleton: the Owen point is presented. Finally, the authors point out the relationship of the Owen point with some well-known worth allocation rules in cooperative game theory.

Later, Guardiola et al. (2007b) prove that the class of PI-games coincides with the class of PMAS-games, and they provide an interesting relationship between PI-games and concave games. In addition, they present three different axiomatic characterizations of the Owen point. To achieve the two first characterizations they have kept in mind the work by

Gellekom et al. (2000) in which the Owen set of linear production games is characterized. The third one, which is based on a population monotonic property, is very natural due to the fact that the class of PI-games coincides with the class of non-negative cost games with a pmas.

The study of coordination in periodic review inventory situations is completed by Guardiola et al. (2006). They consider systems composed by several retailers where each of them has four types of costs: ordering, purchasing, inventory holding and backlogging costs. It is assumed that each single component in the system is the backlogging extension of the well-known Wagner & Whitin model, which Zangwill (1969) solved by dynamic programming techniques. In their approach coordination means that retailers share their holding technologies and ordering channels. Therefore, when a coalition of retailers is to form (joint venture) each retailer works with the best holding technology and ordering channels among the members of the coalition. This means that the members of that coalition purchase, hold inventory, pay backlogged demand and make orders at the minimum cost of the coalition members. Cooperation in holding and purchasing is usual and has appeared already in literature. Their mode of cooperation in backlogging is also standard although new: once a coalition is formed, all its members pay compensation to customers for delayed delivering (backlogging cost) of their demands according to the cheapest cost among the members in the coalition. In some regard, larger coalitions are stronger and can "squeeze" their clients a bit more. It is obvious that the above coordination process induces savings and therefore, studying the problem of how to allocate the overall saving among the retailers is a meaningful problem. Once again this allocation problem can be modelled by a transferable utility cooperative game. In this game the characteristic value of each coalition of retailers is obtained solving the combinatorial optimization problem that results from Zangwill's model induced by the members of the coalition.

Closer to Guardiola et al. (2006, 2007a) are papers that focus on cooperation in periodic review inventory situations by means of cooperative game theory. One of the papers to do so is Van den Heuvel et al. (2007), which studies coordination in economic lot sizing situations (henceforth, ELS-situations). In that finite horizon model, players should satisfy the demand in each period by producing in that period or carrying inventory from previous periods; backlogging is not allowed. The main difference between that model and the one given by Guardiola et al. (2007a) is that the former considers setup costs but assumes that costs are the same for all players in every period. Therefore, ELS- and PI-situations are pairwise distinct, in general. The main result in Van den Heuvel et al. (2007) is that ELS-games (games induced by ELS-situations) have a nonempty core. In another paper, Chen & Zhang (2007a) propose an integer programming formulation for the concave minimization problem that results from an ELS-situation and show that its linear programming (LP) relaxation admits zero integral gaps, which makes it possible to analyze the game by using LP duality. Here the dual variables are interpreted as the price of the demand per unit.

Guardiola et al. (2006) study a new model of coordination in inventory problems where a group of retailers place periodical orders of indivisible goods considering setup, purchasing, holding and backlogging costs. It leads to a new class of totally balanced combinatorial optimization games called setup-inventory games (henceforth, SI-games). SI-games extend PI-games since the latter do not include setup costs. Notice that if setup cost were zero in all periods, then a PI-situation would arise. SI-games also extend ELS-games since all costs considered can be different for several players in every period and backorders are allowed.

However, ELS-games with concave ordering cost function (see Chen & Zhang, 2007a) do not extend SI-games since, as the former consider a more general ordering cost function, the latter assume that all costs can be different.
All of these characteristics make the model in this paper richer than the previous ones although it is harder to analyze. Guardiola et al. (2006) prove that cooperation in periodic review inventory situations is always stable, i.e. every SI-game has a nonempty core. In addition, they introduce a new family of cost allocations on the class of SI-games: the parametric extended Owen points. It is proven that, under certain conditions, a particular core-allocation can be found (within the parametric family of extended Owen points) for the corresponding SI-game. This point also introduces an important difference with Van den Heuvel et al. (2007), and Chen & Zhang (2007a), who show that ELS-games have a nonempty core, but do not provide any core-allocation.

3.3 Newsvendor games

In a newsvendor setting, the retailers might benefit from cooperation through coordinated ordering and inventory centralization. The cooperation here can be described as follows: the retailers place joint orders for goods to satisfy the total demand they are faced with. In this way, they could get some benefit from coordination of the others and perfect allocation of the ordered amount to the demands realize.
There are several papers that focus on cooperation in inventory centralization in newsvendor settings. One of the pioneers to do so is Eppen (1979), which studies the effects of centralization for inventory models with random demand for each store. He assumes identical storage and penalty costs for each store and in the centralized location, and shows that in this case savings always occur. However, for general demand distributions and store specific holding and penalty costs there might not be any savings from centralization. Conditions on demand distributions are discussed in Chen & Lin (1989) and on holding and penalty costs in Hartman & Dror (2005).
Gerchak & Gupta (1991) investigate a newsvendor game in which each retailer is a newsvendor with identical cost structures and the transportation cost associated with re-allocating inventory after observing the demand is ignored. Hartman et al. (2000) study models with identical newsvendors, focusing especially on the core of newsvendor games. They prove the non-emptiness of the core of these games under some restrictive assumptions on demand distributions: symmetric and joint multivariate normal distribution. Müller et al. (2002) and Slikker et al. (2001) independently develop a more general result, showing that newsvendor games have a non-empty core regardless of the demand distribution. Müller et al. (2002) also provide conditions under which the core is a singleton. The above non-emptiness result is still valid even when there are infinitely many retailers, as proved by Montrucchio & Scarsini (2007). Slikker et al. (2005) enrich the finite model by allowing the retailers to use transhipment (at a positive cost) after demand realization is known. The authors show that newsvendor games with transhipments have a non-empty core even if the retailers have different retail and wholesale prices. Moreover, newsvendor games are not convex in general. Ozen et al (2005) study the convexity of newsvendor games under special assumptions about the demand distributions. Their analysis focus on the class of newsvendor games with independent symmetric unimodal demand distributions. Several interesting subclasses, which only contain convex games, are

identified. Additionally, the authors illustrate that these results cannot be extended to all games in this class.

In several papers, Hartman and Dror analyze cooperation through inventory centralization in a newsvendor setting. Hartman & Dror (2003) study the cost game among the retailers with normally distributed and correlated individual demands. Hartman & Dror (2005) analyze a model of inventory centralization for a finite number of retailers facing random correlated demands. They consider two different games: one based on expected costs (benefits), and the other based on demand realizations. The authors show that, for the first game, the core is non empty when holding and shortage costs are identical for all coalitions of retailers, and demand is normally distributed. However, the core might be empty when the retailers' holding and penalty costs differ; they derive conditions under which such a game will be subadditive. For the second game, the core can be empty even when the retailers are identical.

There are other papers which examine the existence of stable profit allocations among cooperative retailers by means of the so called stochastic cooperative decision situations (see Ozen, 2007). Ozen et al (2006) analyze the stability of cooperation among several outlets who come together to benefit from inventory centralization. The authors focus on newsvendor situations with delivery restrictions. In these situations, the retailers dispose some restrictions on the number of items that should be delivered to them if they join a coalition to benefit from joint ordering. They show that the associated cooperative game has a non-empty core. Afterwards, they concentrate on a dynamic situation where the retailers change their delivery restrictions. They then investigate how the profit allocation might be affected by these changes. Another example of newsvendor situations is considered in Ozen et al (2007). They study newsvendor situations with multiple warehouses, where the retailers can cooperate to benefit from inventory pooling. The warehouses offer alternative ways of supplying the goods to the retailers, which might become more useful when the retailers form coalitions. The authors study the corresponding cooperative game and they prove that the core of these games is nonempty. In the previous papers, the cooperation among retailers through the coordination of their orders and allocation of these orders after demand realization has been considered. Sometimes, however, it may not be possible to allocate the orders after exact demand realizations. In such situations, the retailers can only satisfy their customers from the stock at their local facilities. However, if the retailers could obtain better information about future demand while their orders are on the way, they would still be able to benefit from inventory centralization by reallocating their orders when they arrive at the facility where the reallocation can take place after demand information update (e.g., port, warehouse, etc.). Ozen & Sosic (2006) consider newsvendor situations with updated demand distribution. They investigate the associated cooperatives games between the retailers and show that such games are balanced.

A very recent paper by Chen & Zhang (2007b) presents a unified approach to analyze the newsvendor games using the duality theory of stochastic programming developed by Rockafellar & Wets (1976). The optimizations problems corresponding to the newsvendor games are formulated as stochastic programs. The authors observe that the strong duality of stochastic linear programming not only directly leads to the non-emptiness of the cores of such games, but also suggests a way to find a core-allocation. The proposed approach is also applied to newsvendor games with concave ordering cost. Additionally, they prove that it is

NP-hard to determine whether a given allocation is in the core of the newsvendor games even in a very simple setting.
The newsvendor inventory centralization problem examined in the literature is geared mainly to the expected value cost analysis. However, minimizing expected centralized inventory cost might not be a very convincing argument for centralization. A build-in cost allocation mechanism should provide additional incentives for cooperation. That is, in each time period the stores reflect on the actual performance of the system in relation to the anticipated long-run expected performance. The analysis of an on-line system cost allocation(s) performance versus the performance in expectation is the main topic of Dror, et al (2007). They examine a related inventory centralization game based on demand realizations that has, in general, an empty core even with identical penalty and holding costs (Hartman & Dror, 2005). They then propose a repeated cost allocation scheme for dynamic realization games based on allocation processes introduced by Lehrer (2002). It is proven that the cost sub-sequences of the dynamic realization game process, based on Lehrer's rules, converge almost surely to either a least square value or the core of the expected game. To complete this study, they extend the above results to more general dynamic cost games and relax the independence hypothesis of the sequence of players' demands at different stages.

4. Retailer-supplier relationships

The previous section discussed cooperation among retailers only, or in other words, horizontal cooperation within a supply chain. This type of cooperation is concerned with collaboration among parties in a chain that are on the same level and perform similar tasks. This section concentrates on vertical cooperation, that is, collaboration among parties in a chain that are on adjacent levels, like a supplier and retailer. Hence, these parties perform different tasks, which ask for another type of cooperation than in case of horizontal cooperation. Important aspects of cooperation include the coordination of actions to maximize joint profits.
Vertical cooperation within a supply chain may take different forms ranging from the coordination of actions to a full merger of the parties involved. In the first case, coordination of actions, the parties remain economically independent and act under decentralized control, that is, each party takes its own decision. Nevertheless, the coordination that the parties agreed upon makes sure that each of them improves upon its profits. Because of decentralized control and the conflicts of interests, these situations are often studied with non-cooperative game theory. We refer the reader to Cachon & Netessine (2004) for a review on this area of research. A merger of parties is another extreme with regard to vertical cooperation. In this case, all parties give up their independence and will be under centralized control. The new merger decides upon actions for all (former) parties. Such a merger will only be formed if there is a win-win situation for all of the parties.
In all cases, parties or firms in a chain are only willing to cooperate if none of them can do better otherwise. A natural tool to study this is cooperative game theory. In particular TU-games are useful to decide whether cooperation is stable and how to maintain it by means of some allocation of the joint profits among the parties involved. It is surprising to learn that only a few papers study vertical cooperation in a supply chain by means of cooperative game theory, and by TU-games in particular. Therefore, we believe that it is a new and exciting area of research on supply chains.

Within cooperative game theory, bargaining games are the most popular tools to study cooperation among supply chain partners. There are two recent reviews that pay attention to bargaining models. Sarmah et al. (2006) provide a review on supplier-retailer models in supply chain management. The authors focus on coordination models in supply chain management that use quantity discounts as a coordination tool in a deterministic environment. The only cooperative coordination models mentioned are the cooperative bargaining games. All other coordination models are studied with non-cooperative game theory. Another review by Nagarajan & Sošić (2006) also considers cooperation among supply chain partners. They focus on two important aspects of cooperative games, namely on profit allocation and stability. First, attention is payed to bargaining games for profit allocation. Thereafter, coalition formation among parties in a supply chain is surveyed.

As far as we are aware, the only paper that uses TU-games to study vertical cooperation in a supply chain is Guardiola, Meca and Timmer (2007). In this paper, distribution supply chains with one supplier and multiple retailers under decentralized control are studied. Cooperative TU-games are used to study the stability and the gains of cooperation. Cooperating retailers may gain from quantity discounts, while a supplier-retailer cooperation results in reduced costs. The authors show that the corresponding TU-games are balanced, that is, cooperation is stable. They also propose a specific allocation of the joint profit that always belongs to the core of the game. This does not hold for the Shapley value, a well-known solution for TU-games. Another property of the proposed allocation is that properly valuates the supplier since it is indispensable to obtain a maximal gain in profits.

5. Conclusion and future research

In this chaper, we have reviewed and surveyed the literature on supply chain collaboration. As mentioned above, the game theory models that include cooperative behaviour among retailers seem to be a natural framework to model cooperation (collaboration) in supply chains that consist of a supplier and a finite number of retailers. Various researchers in this area have already adopted several cooperative models dealing with supply chain coordination, and it is expected to see many more in the near future since, as you may notice, this is a rather new area of research in supply chain management.

One level of supply chain collaboration is the inventory centralization. The main focus of concern here is to examine the effects of horizontal cooperation (cooperation among the retailers only). The first step is to study cooperation in continuous review inventory situations through out the class of inventory games. We can conclude that any collective of retailers can reduce its joint inventory costs by means of cooperative behaviour. Additionally, they can always find stable (core-allocations) and consistent (sustained as pmases) allocation rules, which therefore encourages them not to form sub-coalitions during the cooperative process. This wide class of games arises when considering joint ordeing and holding in the basic inventory situations (EOQ and EPQ). Some nice additons to this umbrella of games are the holding games introduced by Tijs et al (2005), and the collaborative procurement for the EOQ model with multiple items proposed by Hartmand & Dror (2007). There are numerous oportunities to create new inventory centralization models that extend the ones already studied and can be included in the class of inventory games. We hope to see and, why not, do many more in the future.

The second step is to consider the dynamic extension of inventory games. It is the periodic version of the above model with finite horizon and time varying demand. Several papers in the field have analyzed cooperation in finite horizon periodic review inventory situations (see Guardiola et al. 2007a,b, Van Den Heuvel et al. 2007, and Chen & Zhang, 2007a). Nevertheless, those papers only consider partial aspects of the general problem. In Guardiola et al. (2006) a new model is introduced that incorporates all relevant costs and that, in some sense, includes the models in the above references as particular instances. In their model agents share ordering channels and holding and backlogging technologies so that the resulting coordination inventory model induces savings. These savings can be distributed among any group of agents in a stable way since the corresponding cooperative game is totally balanced. Moreover, for this class of games (SI-games), the authors define a parametric family of allocations that extends the rationale behind the Owen point (see Guardiola et al. 2007a,b) and identify an important subclass of SI-games where an extended Owen point can be attained by means of a pmas.

In some respects Guardiola et al. (2006) unifies the treatment of coordination in periodic review inventory situations (all relevant costs are included). In addition, it proves that this type of coordination makes sense since induces savings that can be allocated without being blocked by any member of the group (the cooperative game induced by the model is totally balanced). This stability is rather appealing and invites to pursue new investigations that increase efficiency in coordinated models of inventory operation. Some of these additional topics for further research are: (1) investigating coordination in dynamic inventory situations with concave cost functions; and (2) exploring new models of periodic review inventory problems with shipping costs.

The third step we centre our attention on presenting cooperation in multiple newsvendor settings. In such frameworks, newsvendor games arise and are studied. The main result here is that the retailers can always get some benefit from cooperation through coordinated ordering and inventory centralization. In addition, there always exist stable profit allocations among cooperative retailers. However, the problem of determining whether a given allocation is stable or not is sometimes an NP-hard optimization problem even in a very simple newsvendor setting.

A different type of collaboration is vertical cooperation in supply chains. Most of the literature up-to-date studies a supplier-retailer with non-cooperative game theory. For a proper analysis of all cooperation possibilities, the application of cooperative game theory is necessary. This is a rather new area of research with a limited number of papers. Most of these use bargaining games to study negotiations and profit allocation between the supplier and the retailer. As far as we are aware, only Guardiola et al., (2007) use TU-games to study collaboration in a distribution chain with a single supplier and multiple retailers. This new area of research has lots to explore yet. TU-games can be used to analyse stability of collaboration within all sorts of supplier-retailer relationships. Further, aspects like nonzero leadtime, stochastic demand, and incomplete availability of information on costs should be included. Other interesting research includes situations in which the retailers provided by the supplier are competitors on the same market, or situations of collaboration within a supply chain that involves three or more levels, like a manufacturer, supplier and a retailer.

Other than the ones already mentioned, some other ongoing and future research topics in supply chain collaboration are presented below.

5.1 Cooperation in multi-supplier supply chains with bounded demand

In this section, we propose to exted the study of retailer-supplier relationships in supply chains with a finite number of suppliers and retailers, and random demands. The main focus of concern is to analyze the impact of such cooperation on the suppliers, retailers, and supplier-retailer interactions.

The starting point is the paper Guardiola et al., (2007) that, as we already announced, studies the coordination of actions and the allocation of profit in supply chains under decentralized control in which a single supplier supplies several retailers with goods for replenishment of stocks. In our multi-supplier and bounded demand framework, the main goal of the suppliers and the retailers is also to maximize their individual profits. Since the outcome under decentralized control is inefficient, cooperation among firms by means of coordination of actions may improve the individual profits. Cooperation is studied by means of cooperative game theory. First, we examine whether or not the cooperative game corresponding to this multi-supplier and bounded demand situation is balanced. Then we will look for an (stable) allocation rule that satisfies good properties for these games.

5.2 Cooperation in assembly systems: the role of knowledge sharing

In this section, we analyze a production system similar to that of Toyota. Based on this model, we investigate the costs, benefits, and challenges associated with establishing a Knowledge Sharing Network (see Dyer & Hatch 2004).

We consider an assembly system with one assembler (for example, Toyota) purchasing components from several suppliers. Demand is deterministic and each supplier faces holding and fixed ordering costs (i.e., a stationary model, not necessarily time-dependent). For a given set of costs and demand rates, there is no exact solution, but one can construct a solution that is very close to optimal (see Zipkin, 2000). This model has some similarities both with Guardiola et al. (2007a) and Meca et al. (2004).

We model process improvement by considering reductions in the fixed costs. In a knowledge sharing network, suppliers are placed in groups to share knowledge about best practices. In our setting, suppliers within each group achieve, through knowledge transfer, a fixed cost equal to that of the supplier with the lowest fixed cost in the group. This idea is similar to that proposed in Guardiola et al. (2007a), in which all firms incur the fixed cost of the most efficient company.

We model knowledge transfer through a cooperative game and focus on reductions in fixed costs. In this setting, we explore the feasibility of knowledge sharing, by investigating the existence of payment transfers that make all firms better off with cooperation (i.e., the core of the corresponding game is non-empty). In addition, if the core is non-empty, we study properties of the core and compute core-allocations.

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2

Towards a Quantitative Performance Measurement Model in a Buyer-Supplier Relationship Context

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1. Introduction - problem statement

In the current industrial context, it is generally difficult for manufacturing companies to produce all the components of the products they propose. Thus, they either buy a large proportion of these components from suppliers or subcontract their manufacturing with other companies. This exchange of physical and informational flows between buyers and suppliers is then considered as a network. In terms of manufacturing and logistics, this network can be seen as a Supply Chain (SC) which connects the ultimate customer (buyer) to the ultimate supplier (Ayers, 2000) (Barut et al., 2002). On the other hand, the SC management requires an effective cooperation between suppliers and buyers. In this sense, the whole SC from raw material suppliers to the final customer can be seen as a set of buyer-supplier relationships. It means that the buyer-supplier relationship is the cornerstone of the SC management (Kelle et al., 2007).

One important point in the SC management concerns the measurement of the performance (Gunaserakan et al., 2008). Indeed, according to Deming's wheel, SC management requires performance indicators which handle:

- on the one hand the objectives, to be defined consistently with the capabilities of the considered system,
- on the other hand the measures of the achievement of the assigned objectives, in order to asses the achieved improvement and define the next actions to implement.

The performance measurement remains a difficult problem for companies as well as SC's. We choose here to subscribe to the performance vision based on the ISO 9000 standard. In this sense, the current scorecards generally collect sets of performance measurements about the main processes of the SC, usually according to the SCOR model (SCOR, 2000). Nevertheless, the question of the overall performance resulting from the process performances is rarely considered. Indeed, performance indicators are associated to each process. However, the provided performances are independently defined, as each process is evaluated separately from the others. This partitioned vision does not allow to consider SC as a whole and thus to efficiently control it. In this sense, the involved indicators must be supplemented by the knowledge of the links between them. Therefore, the interest for an overall performance expression for all or a part of the SC is acknowledged, as is the case for

process control in individual companies. Indeed, for a SC considered as a whole, this expression can help decision-makers in many situations.
The aim of our proposition is the overall performance quantification in a SC context, through the handled set of buyer-supplier relationships. The work here presented is based on the synthesis of previous studies in this field (Clivillé & Berrah, 2005), (Berrah & Clivillé, 2007). More precisely, the idea is to extend the proposed approaches to the case of individual companies. In this sense, this chapter is organized as follows. In section 2, some generalities about the SC are recalled. Section 3 deals with the industrial performance measurement, first with a review of Performance Measurement Systems (PMS's) from a general point of view. Then we focus on the proposed quantitative performance measurement model. The considered model for the SC is the SCOR one while the process performance quantification is supported by both the multicriteria MACBETH methodology and the 2-additive Choquet Integral operator. Then, in section 4, an overall performance measurement framework is presented through a case study submitted by a bearings manufacturer.

2. Some generalities about the SC

Among the propositions made to model the SC (Villa, 2001) the SCOR (Supply Chain Operations Reference) model (SCOR, 2000) proposes to distinguish 4 abstraction levels, going from the more generic one (level 1) to the more particular (level 4) (figure 1). At level 1, each company of the SC is described through 5 processes: *Plan – Source – Make – Deliver – Return*. At level 2, these processes are specified (e.g. the *Source* process is identified in the S1 process *i.e. Source Stocked Product* process, or the S2 process *i.e. Source Make-to-Order Product* or the S3 process *i.e. Source Engineer-to-Order Product*). At level 3, the processes of level 2 are deployed into sub-processes according to the company organization. At level 4, the activities which constitute the sub-processes are defined specifically w.r.t. the organization of the company. According to the previous definitions, the SCOR model takes the different SC flows into account in a common manner. Indeed, the set of categories of processes and sub-processes is able to represent the different types of manufacturing organisation. So, it is easier for the decision-makers to consider the whole SC, which is a necessary condition for the management to consider the consequences of their decision (Berrah & Clivillé, 2007).
Besides, the measurement of the SC performance (Beamon, 1998) remains a difficult problem (Angerhofer & Angelides, 2006), which is often handled in two different ways:

- the SC performance is the result of, respectively, the intra-organisational performance of the different companies implied in the SC and, the performance of the interaction between the different companies of the SC (Angerhofer & Angelides, 2006),
- the SC is conventionally seen as a particular process, and its performance is thus expressed w.r.t. the process recommendations of the ISO 9000 standard (Clivillé et al., 2007).

According to the second approach, the current scorecards generally collect sets of performance measurements from the processes of the SC, usually w.r.t. the SCOR model. As an illustration, Gunaserakan collects, in table 1, the main strategic, tactical and operational indicators, according to the *Plan – Source – Make - Deliver* processes of SCOR (Gunaserakan et al., 2004).

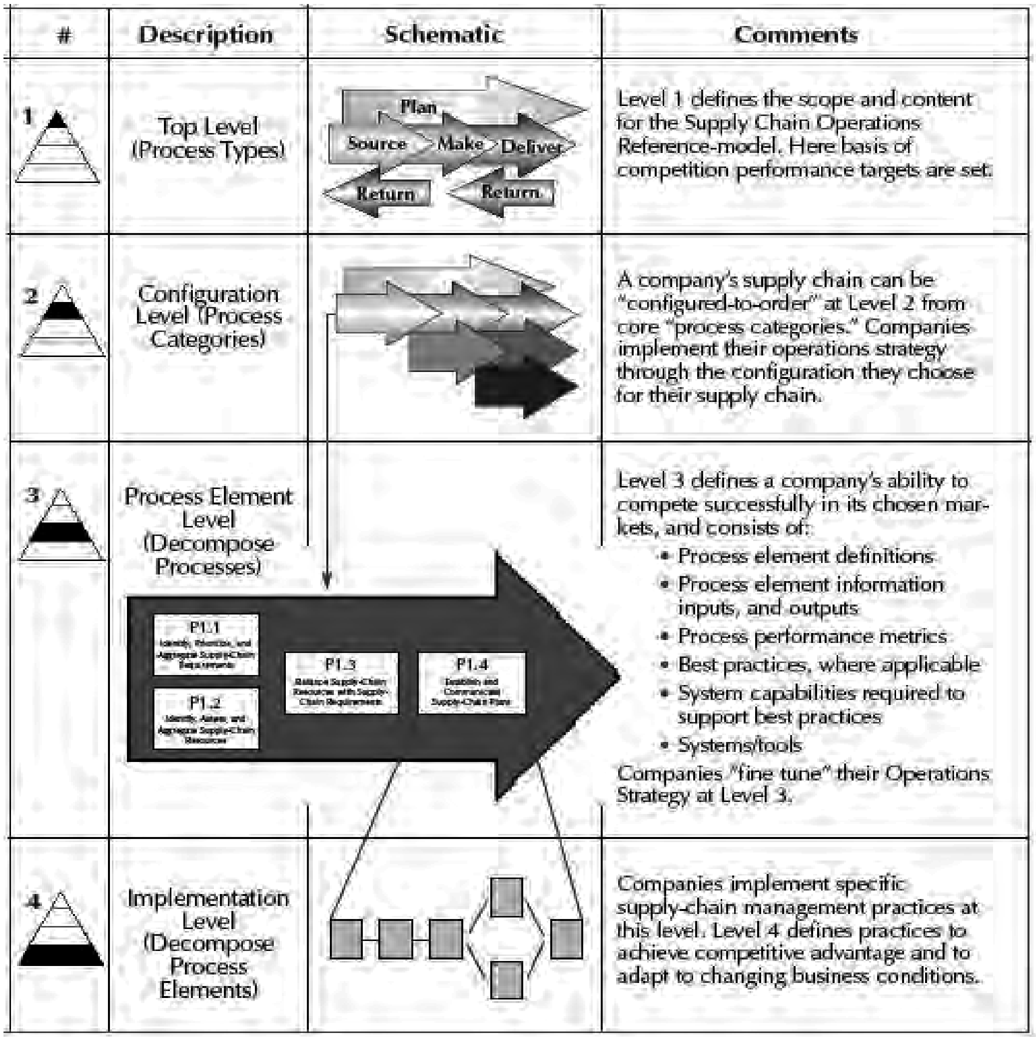


Figure 1. The SCOR model (SCOR 80, 2007)

Note that in this case, no strategic indicators are associated to the *Source* process. Nevertheless, we can imagine similar measures as for the tactical level, such as delivery, lead time, pricing… Moreover, the question of the overall performance resulting from the process performances is rarely approached. Indeed, performance indicators are associated to each process of SCOR, thus providing information for the control. As viewed before, this practice induces a risk because each process is separately evaluated from the others.

This partitioned vision does not allow to consider SC as a whole and thus to efficiently control it. In this sense, the involved indicators must be implemented by information concerning the links between them (Lohman et al., 2004) (Blanc et al., 2007). Therefore, the interest for an overall performance expression for all or a part of the SC is acknowledged, as is the case for process control in individual companies. Indeed, for a SC, this expression can help decision-makers (Chan, 2003):

- to compare different organizations (e.g. the location of the warehouses),
- to manage and improve the whole SC (e.g. a change of supplier, the transition from *make-to-stock* to *assembly-to-order*…),
- to diagnose the main causes of an unsatisfactory overall performance,
- to benchmark all or a part of the SC (e.g. the delivery reliability is worse than the median of the class).

SC activity/ process	Strategic	Tactical	Operational
Plan	Level of customer perceived value of product, Variances against budget, Order lead time, Information processing cost, Net profit Vs productivity ratio, Total cycle time, Total cash flow time, Product development cycle time	Customer query time, Product development cycle time, Accuracy of forecasting techniques, Planning process cycle time, Order entry methods, Human resource productivity	Order entry methods, Human resource productivity
Source		Supplier delivery performance, supplier lead time against industry norm, supplier pricing against market, Efficiency of purchase order cycle time, Efficiency of cash flow method, Supplier booking in procedures	Efficiency of purchase order cycle time, Supplier pricing against market
Make/ Assemble	Range of products and services Percentage of defects, Cost per operation hour, Capacity utilization	Utilization of economic order quantity	Percentage of Defects, Cost per operation hour, Human resource productivity index
Deliver	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule, Effectiveness of delivery invoice methods, Percentage of finished goods in transit, Delivery reliability performance	Quality of delivered goods, On time delivery of goods, Effectiveness of delivery invoice methods, Number of faultless delivery notes invoiced, Percentage of urgent deliveries, Information richness in carrying out delivery, Delivery reliability performance

Table 1. SC performance indicators.

Our study is based on the SCOR model. We look for the overall performance quantification of a SC on the one hand and the explanation of the different involved links on the other hand. In the following sections, we are going to formalize this performance, by making first a literature review.

3. The industrial performance measurement

3.1 A brief literature review

The purpose of performance indicators is, on the one hand, to give pieces of information about the satisfaction of the assigned objectives and on the other hand to link the current measures to the improvement actions to launch (Berrah & Mauris, 2002) (Bitton, 1990) (Fortuin, 1988). In this sense, so-called Performance Measurement Systems (PMS's) are the instruments to support decision-making (Bititci, 1995) (Ghalayini et al., 1997) (Globerson, 1985) (Kaplan & Norton 1992) (Neely, 1999) (Clivillé, 2004) in continuous improvement processes.

From a global point of view, a PMS can be seen as a multi-criteria instrument, made of a set of performance expressions (also referred to as metrics by some authors (Melnyk 2004)), *i.e.* physical measures as well as performance evaluations, to be consistently organized with respect to the objectives of the company (Berrah et al., 2000) (Clivillé et al., 2007a). A PMS is defined w.r.t. a global objective and at the end, provides one or a set of performance expressions in order to quantify the satisfaction of this objective.

Generally, the considered global objective is broken down into elementary ones along organizational levels (strategic, tactical or operational) (Grabot, 1998) (Gomez et al., 2001), while the elementary performance expressions associated to the broken-down objectives can be aggregated, providing information about the global satisfaction. As will be seen later, such a quantitative break-down/aggregation performance measurement model (Berrah et al., 2004) (Clivillé et al., 2007a) has been proposed for the performance improvement process control, being thus a support for decision-making. Indeed, there are limits to the decision-maker's ability to process large sets of performance expressions. So, a more synthesized piece of information completes the numerous considered scorecards, leading thus to a global vision of the involved processes. More particularly, the established links between overall and elementary performance expressions allow explanation and diagnosis of the objective's satisfactions according to the different reached performances, leading thus to choose or launch improvement actions (Bititci, 2001) (Clivillé, 2004). More precisely, it is well known that one challenge of control is to identify "coalitions" of improvement between different areas in as efficient as possible a way (Clivillé & Berrah, 2007b).

More particularly, in this sense, one major problem in PMS modelling concerns two points:

- the identification of the performance structure, *i.e.* on the one hand the elementary criteria which contribute to the global objective and, on the other hand, the coherent expression of the performances which reflects the objective's satisfactions according to the different criteria,
- the identification of the links between the elementary expressions and the overall one in order to express the global objective's satisfaction.

The performance structure is widely considered in the literature. Indeed, most of the PMS proposals are logical frameworks for linking strategic objectives and structuring the tactical and operational criteria affecting them as shown in table 2.

The link identification problem is handled w.r.t. the aggregation of the elementary performance expressions. The performance aggregation is often defined as the corollary step of the break-down of the objectives. This operation deals with the combination of all the associated performance expressions. In this sense, two PMS types are distinguished, the mono-criterion PMS and the multi-criteria PMS, as shown in table 3.
Note that the performance expressions are generally considered independently from one another. They are usually provided from the comparison of the assigned objectives and the measures which describe the considered processes or activities' enactment. These measures usually come from physical sensors or human operators. Nevertheless, according to Taylorian local control, performances can be simply quantified by physical measures or by productivity ratios. But in a multi criteria vision, the coherence between elementary and aggregated performances becomes necessary.

PMS model	Focuses
SMART (System Measurement Analysis and Reporting Technique) model (Cross & Lynch, 1988-89)	Break-down of the objectives of the company along 4 levels – company, business units, business operating units and departments and work centres - according to 10 measures such as delay, quality, customer satisfaction…
ABC/ABM (Activity Based Costing/Activity Based Modelling) model (Brimson, 1991)	Identification of the activities and processes which generate value in the company and the factors which induce this value production.
Balanced Scorecard BSC (Kaplan & Norton, 1992, 1996)	Definition of 4 axes (criteria) - processes, organisational learning, financial and customers - in order to express company performance.
PPMS (Process Performance Measurement System) (Kueng & Krahn, 1999)	Measurement of the company performance according to 5 aspects - financial, innovation, customer, societal and employee.
ECOGRAI (Bitton 1990) (Ducq et al., 2001)	Identification of 3 criteria - delay, quality and cost – for all the processes/activities of the company.
Quantitative Breakdown/Aggregation Performance Measurement model (Clivillé et al. 2007a)	Identification of the performance indicators and their organization for a reactive control according the systemic approach

Table 2. The major PMS models

According to the measurement theory (Kranz et al., 1971), ensuring the coherence requirement in the performance quantification process implies that:

- the elementary expressions must be «commensurate», *i.e.* two identical values (e.g. 0.8) according to two different criteria (e.g. *Lead_time* and *Quality*) must have the same meaning for the decision-makers,
- the aggregation operator must be «significant» w.r.t. the elementary expressions. For example, if the aggregation operator is the arithmetic mean, the significance condition is translated into the following proposition: for each criterion, the same difference between two values must have the same meaning (e.g. [0.8 - 0.5] and [0.4 - 0.1]). This condition ensures that an elementary performance can be compensated by another one.

Now, if the aggregation operator is the product, the condition will not concern the difference but the ratio.

PMS model	Type	Aggregation mechanism
Accounting (Johnson, 1975)	Mono criterion	Addition of elementary costs
ABC (Berliner & Brimson, 1988) (Cooper & Kaplan, 1988)	Mono criterion	Addition of elementary costs according to company Activity Based Model
Time based performance measures (Azzone et al., 1991)	Mono criterion	Addition of elementary durations
PCS (Performance Criteria System) (Globerson, 1985)	Multi criteria	Aggregation of "critical" performances thanks to the Weighted Arithmetic Mean (WAM)
ECOGRAI (Bitton 91) (Ducq et al., 2001)	Multi criteria	Aggregation of 3 criteria - delay, cost, and quality – thanks to specific aggregation operators - *min, max, sum* – w.r.t. both the involved criterion and the combination type of the activities - *or, and, sequence* – in processes
QMPMS (Quantitative Model Performance Measurement System) (Bititci 1995) (Suwignjo & Bititci, 2000),	Multi criteria	Identification of the criteria to be considered thanks to a cognitive map and aggregation thanks to the WAM operator. Integration of a corrective factor to take interactions between criteria into account. Using of the AHP methodology to define weights.
Quantitative Breakdown/Aggregation Performance Measurement model (Clivillé et al. 2007a)	Multi criteria	Identification of the criteria to be considered thanks to a cause-effect diagram and aggregation thanks to the Choquet Integral (CI) operator. Using of the MACBETH methodology to identify both elementary expressions and CI parameters

Table 3: The different aggregation approaches

The Analytic Hierarchy Process (Saaty, 1977, 2004) methodology was the first to deal with this awkward task. Ratio scales[1] are built from human expertise in order to quantify the weights of the WAM operator. In this approach, the required determination of an "absolute" null performance remains a difficult task in an industrial context where the performance is particularly relative. In the same way, the MACBETH (Multi Attractiveness Categorical Based Evaluation TecHnique) methodology (Bana e Costa et al., 2003) (Bana e Costa et al., 2004) (Clivillé, 2004) (Clivillé et al., 2007a) has been used to coherently express both the elementary and aggregated performance expressions. In MACBETH, these conditions are ensured thanks to the building of particular scales, well adapted for the family of arithmetic

[1] For the sake of conciseness, the scale aspect is not developed in this article. It is possible to find more information about ordinal, interval, ratio scales in (Bane e Costa et al., 2003) (Kranz et al., 1971).

mean operators (in accordance with the measurement theory). Moreover, in a context where the criteria are interdependent, the Choquet Integral (CI) operators can be used. This operator family generalizes the WAM operator by taking mutual interactions between criteria into account (Berrah et al., 2004) (Grabisch, 1997) (Grabisch & Labreuche, 2004) (Marichal, 2000).
Let us now focus on the mechanism of performance quantification, as it is adopted in the quantitative breakdown-aggregation performance measurement model mentioned before, and which is based on the MACBETH methodology illustrated by the figure 1.

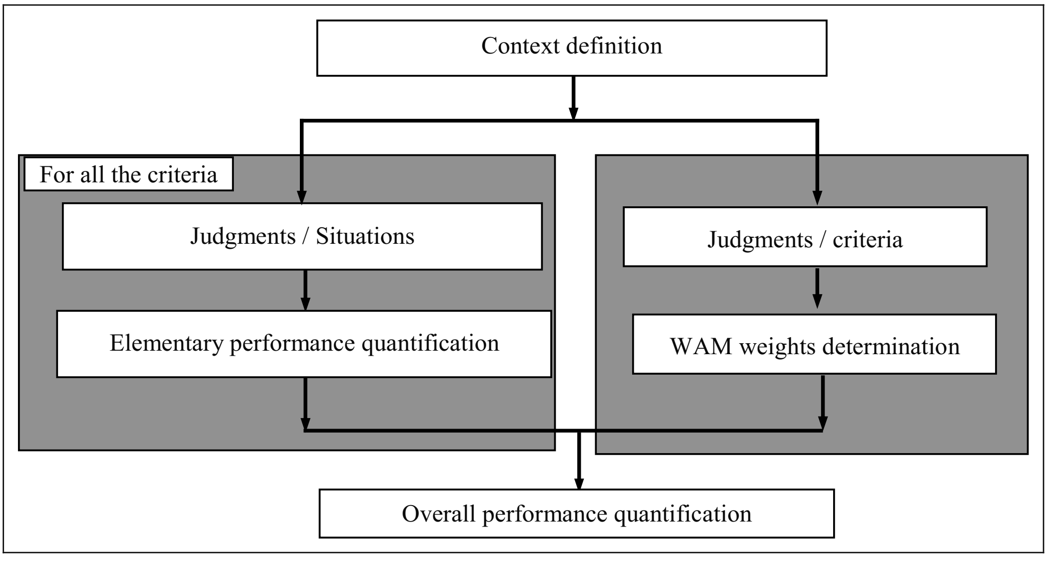


Figure 1. The MACBETH methodology.

3.2 The mechanism of performance quantification

3.2.1 Description of the problem

The quantification of the performance expressions can be viewed as a procedure which, in a first step, quantifies the elementary performances. The second step then consists in their synthesis in an overall performance expression, generally thanks to an aggregation operator. Hence, the performance aggregation can be formalized by the following mapping (Berrah et al., 2004):

$$Ag: \quad E_1 \times E_2 \times \ldots E_i \times \ldots E_n \times \rightarrow E$$

$$\left(p_1, p_2 \ldots, p_i \ldots, p_n\right) \rightarrow p_{\mathrm{Ag}} = Ag\left(p_1, p_2 \ldots, p_i \ldots, p_n\right)$$

The E_{i} 's are the universes of discourse of the elementary performance expressions $\left(p_1, p_2 \ldots, p_i \ldots, p_n\right)$ and E is the universe of discourse of the overall performance expression p_{Ag} . As the universes E_i 's and E can be different, the determination of the aggregation mapping Ag is generally not straightforward.

Example: Let us consider a simple example from (Gunaserakan et al., 2004) with 4 criteria about the *Source* process performance. In order to compare the different suppliers for improving the buyer-supplier relationships, let us imagine that we need to aggregate the performances related to the 4 following criteria: the *Lead_time*, the *Quality*, the *Cost_saving_initiatives* and the *Supplier _pricing* (Figure 2).

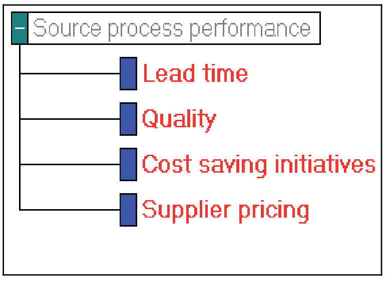


Figure 2. The criteria for the Source process performance

For a given supplier, let us consider it possible to express the following elementary measures: $m_1 = 12 days$ for the *Lead_time*, $m_2 = 99{,}3\%$ for the *Quality*, average_*delay* $m_3 = 30$ K€ for the *Cost_saving_initiatives* and $m_4 = 13.5$ € for the *Supplier _pricing*.

In this case, directly determining the supplier overall performance is an awkward task. One way to simplify this problem is to translate the elementary measures into satisfaction degrees, so called elementary performance expressions, and to define the links between the local satisfactions and the global one by the weighted mean for instance. Indeed, the aggregation operation can be performed if and only if the elementary performances are expressed and the aggregation operator is selected and defined.

3.2.2. Elementary performance expression

Generally speaking, the transformation of physical measures into performance expressions can be given according to the following mapping (Berrah et al., 2004):

$$P: \quad O \times M \rightarrow E$$

$$(o, m) \rightarrow P(o, m) = p$$

O, M and E are respectively the universes of discourse of the set of objectives *o*, of the set of measures *m* and of the performance expression p . The key point in differentiating this kind of performance expression from conventional measurements is the comparison of the acquired measures with an objective defined according to the control strategy considered. Thus, the mapping P denotes a comparison operator such as a distance operator or a similarity operator (Berrah et al., 2004).

But we have already highlighted that the elementary expressions have to be commensurable and the aggregation operator must be significant for this expression (Grabisch et Labreuche, 2004). To respect these two points, rather than using a direct comparison operator, MACBETH proposes to define interval scales on [0,1] elaborated thanks to decision-makers' judgments (Bana e Costa & Vansnick, 1997) (Vansnick, 1984).

Example: Let us consider the previous example. Table 4 gives the judgments of the SC decision-maker concerning the *Lead_time* criteria w.r.t. 3 different steel furniture suppliers, S1, S2, and S3. These suppliers are thus compared. 2 fictive suppliers are introduced for reference: "*Supplier Good*" which entirely satisfies the considered criteria and "*Supplier Neutral*" which does not satisfy them at all.

Lead time

	Good	S2	S1	S3	Neutral	Current scale
Good	no	v. strong	positive	positive	positive	100.00
S2		no	very weak	positive	positive	61.54
S1			no	moderate	positive	53.85
S3				no	strong	30.77
Neutral					no	0.00

Decision-maker **moderately** prefers supplier S1 to supplier S3

Consistent judgements

Table 4. The SC decision-maker judgments about *Lead_time* (M-MACBETH software[2])

The MACBETH software handles these comparisons and delivers elementary expressions, e.g. the performance of the supplier S2 concerning *Lead_time* is 0.62. In the same way, the decision-makers give their judgments about the other criteria, which allows them to establish the Table 5. At this stage, the results are the same as a scorecard. The decision-maker is able to identify the strengths and the weaknesses of the potential suppliers but he cannot decide which is the best, because there is no Pareto dominance between them. That is why an overall performance associated to each supplier is useful.

	p_1	p_2	p_3	p_4
Supplier S1	0.54	0.55	0.20	0.56
Supplier S2	0.62	0.64	0.50	0.44
Supplier S3	0.31	0.82	0.20	0.67

Table 5. The elementary performance expressions

3.2.3 Determination of the aggregation operator parameters

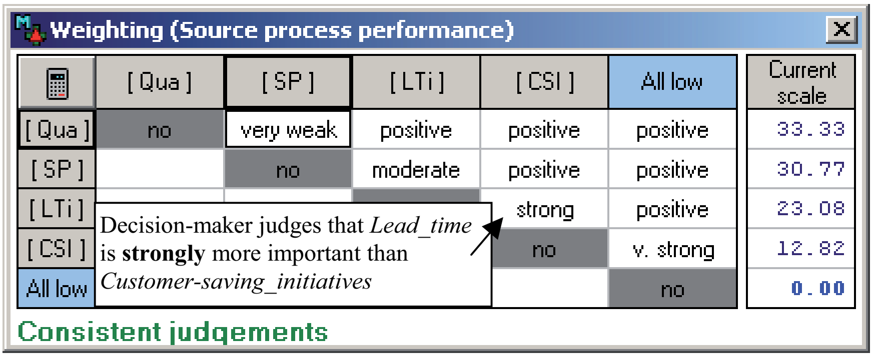
The elementary performances being available, this step concerns the choice of the aggregation operator and thus the determination of its parameters. The most frequently used operator is the WAM (1).

$$\sum_{i=1}^{n} w_i \times p_i \tag{1}$$

[2] A free academic version is available on http://www.m-macbeth.com/

where w_i represents the relative importance of the criteria *i* in the overall performance.

To determine w_i , the decision-maker is asked about the importance of the criteria w.r.t. the overall performance. In this order, he has to express judgments where the relative importances of the criteria are compared. Note that MACBETH also handles this information and allows the SC decision-maker to quantify the weights.
Example: Let us consider our example once again. The decision-maker expresses his judgments about the four identified criteria (Table 6).


Weighting (Source process performance)

	[Qua]	[SP]	[LTi]	[CSI]	All low	Current scale
[Qua]	no	very weak	positive	positive	positive	33.33
[SP]		no	moderate	positive	positive	30.77
[LTi]				strong	positive	23.08
[CSI]				no	v. strong	12.82
All low					no	0.00

Table 6.The decision-maker's judgments about criteria

He considers that the *Quality (Qua)* criterion is more important than the *Supplier pricing (SP)* criterion in a supplier selection process. The difference between the 2 criteria is for him "very weak". He also expresses enough comparisons to compare all the criteria. These pair-wise comparisons are considered in a global system by the MACBETH software. The following weights are thus provided (Table 7).

	w1 Lead_time	w2 Quality	w3 Cost_saving_initiatives	w4 Supplier_pricing
Value	0.23	0.31	0.13	0.33

Table 7. The criteria weights

3.2.4 Overall performance expression

By applying the weighted mean operator, an overall performance of each supplier, for the *Source* process, can be expressed as shown in Table 8.

	p1	p2	p3	p4	PAg
Weights	0.23	0.31	0.13	0.33	
Supplier S1	0.54	0.55	0.20	0.56	0.50
Supplier S2	0.62	0.64	0.50	0.44	0.55
Supplier S3	0.31	0.82	0.20	0.67	0.57

Table 8. The aggregated performance expressions

The decision-maker can now rank the suppliers S1, S2, S3. After a validation of his quantification model, he can draw many conclusions:

- retain the best supplier with regards to the overall performance,
- discuss with the best supplier in order to remedy its weaknesses,
- ask the other suppliers to improve their performances,
- launch a new consultation for a better supplier selection.

The decision will be made w.r.t. other supplementary aspects such as, e.g. the previous relations with the suppliers, the portfolio of products outsourced, the perspectives of new product development… in other words the company policy.

3.2.5 The case of imprecise performance expressions

In the previous table, both the elementary and the aggregated performances were precisely expressed. In the industrial decision-making, according to the complex encountered situations, information can be uncertain or imprecise, even linguistically expressed (Berrah et al., 2000). For a selection problem, this imprecision is not necessarily awkward. Indeed, the ranking between the considered solutions is kept if sufficient information is given in another way by the decision-makers. In this sense, MACBETH allows the handling of of imprecise judgments, in both the weights determination and the elementary performance expression. Imprecise aggregated performance is thus provided. The process of quantification of the decision-makers' judgments is modified because the intensities of preferences are translated as, for instance, into fuzzy values (MACBETH scale) instead of crisp values (cardinal scale).

Figure 3 gives an illustration for imprecise handling of the decision-makers' judgments considered before (§ 3.2.2 & 3.2.3).

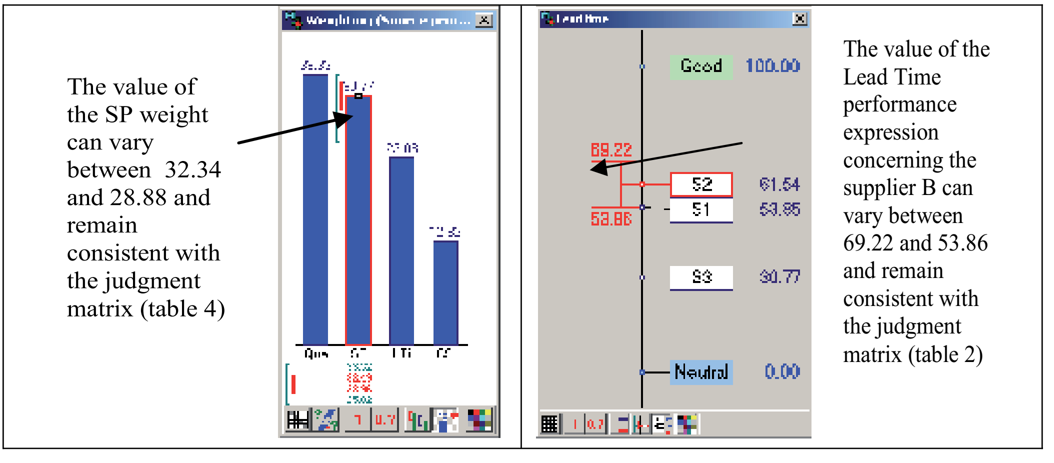


Figure 3. The results of imprecise judgments

Is it possible to compare imprecise aggregated performances? The answer to this question naturally depends on the available information. MACBETH indicates in this sense the necessary information (precise or imprecise) to have w.r.t. the elementary expressions and the weights (Figure 4). For example, to be sure that C supplier is better than A supplier, it is sufficient to have imprecise information concerning the elementary expressions and a ranking of the criteria. On the opposite side, to be sure that supplier C is better than supplier B, it is necessary to have precise values.

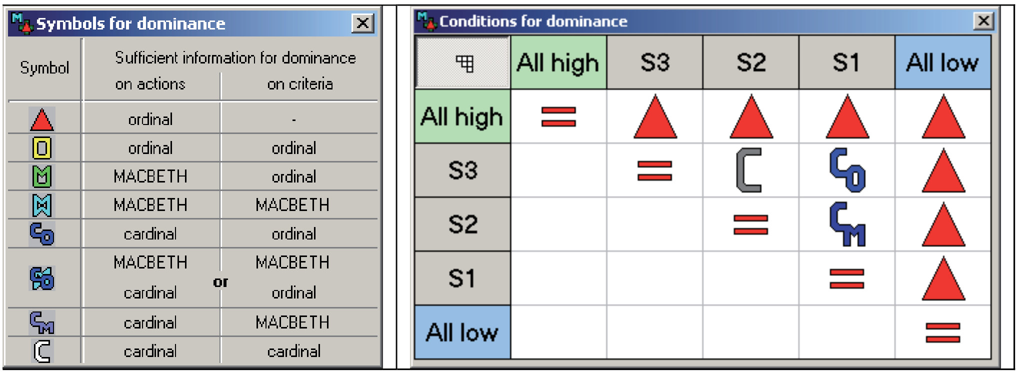


Figure 4. Possible types of comparisons for Suppliers.

4. Case study

The case study concerns a bearings company with its suppliers and deliverers. The company works for automotive and aeronautics companies, spatial and some other high-tech activities. The suppliers are, on the one hand European or Asian steel producers and, on the other hand, SMEs specialized in precision milling and grinding. In order to improve its buyer-supplier relationships, the company overall objective is to subscribe to a total SC point of view and to measure the impact of the defined improvement projects not only on the performance of the company but also on the performance of the SC, namely the 4 main processes according to SCOR, *i.e.* ***Plan, Source, Make, Deliver***[3] (SCOR, 2000) (Gunaserakan et al., 2004) (Figure 5).

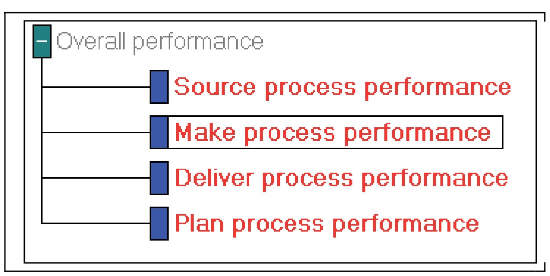


Figure 5. The break-down of the company overall objective

To reach a satisfactory overall performance, the decision-maker defines different improvement projects as alternative solutions:

- the collaboration buyer-supplier relationships (CBS),

[3] The process *Return* proposed in the recent SCOR model is not retained here, its contribution to the overall performance being more complex to handle.

- the Co-Managed Inventory (CMI),
- the e-business solution (EB),
- the low-cost supplier (LCS),
- the Supplier evaluation procedure (SEP).

4.1 Elementary performance expression

Elementary performances are quantified for all the solutions. The complete results are given Figure 6.

Plan process performance

	Good	ERP	CMI	CBS	EB	LCS	Neutral	Current scale
Good	no	moderate	positive	positive	positive	positive	positive	100.00
ERP		no	weak	strong	positive	positive	positive	81.25
CMI			no	strong	positive	positive	positive	68.75
CBS				no	moderate	positive	positive	43.75
EB					no	moderate	positive	25.00
LCS						no	positive	6.25
Neutral							no	0.00

Make process performance

	Good	ERP	CBS	CMI	EB	LCS	Neutral	Current scale
Good	no	strong	positive	positive	positive	positive	positive	100.00
ERP		no	weak	positive	positive	positive	positive	71.43
CBS			no	strong	positive	positive	positive	57.14
CMI				no	very weak	positive	positive	28.57
EB					no	very weak	positive	21.43
LCS						no	weak	14.29
Neutral							no	0.00

Source process performance

	Good	CBS	CMI	ERP	EB	LCS	Neutral	Current scale
Good	no	very weak	positive	positive	positive	positive	positive	100.00
CBS		no	weak	positive	positive	positive	positive	94.12
CMI			no	strong	positive	positive	positive	82.35
ERP				no	positive	positive	positive	58.82
EB					no	v. strong	positive	52.94
LCS						no	strong	23.53
Neutral							no	0.00

Deliver process performance

	Good	ERP	CBS	CMI	LCS	EB	Neutral	Current scale
Good	no	strong	positive	positive	positive	positive	positive	100.00
ERP		no	weak	positive	positive	positive	positive	69.23
CBS			no	moderate	positive	positive	positive	53.85
CMI				no	weak	positive	positive	30.77
LCS					no	very weak	positive	15.38
EB						no	very weak	7.69
Neutral							no	0.00

Figure 6. Elementary quantification for the buyer-supplier relationships improvement

In order to quantify the overall performance, the decision-maker now has to choose an aggregation operator. But, unlike the case exposed in section 3, the decision-maker believes that the criteria are not independent. Namely, there is a strong synergy between the *Plan* process and the *Source* process performances, while there is no link between the *Source* process and the *Deliver* process performances. In this context, the Choquet integral is useful to consider the mutual interaction between the involved criteria.

4.2 Determination of the aggregation operator parameters

Compromise operators are generally considered for making industrial performance aggregation, *i.e.* the aggregate performance is between the minimum and the maximum of the elementary performances. More precisely, the operators of the Choquet Integral (CI) family (Grabisch, 1997) are relevant because they include a lot of generalized mean operators (*i.e.* those included between the min and the max operators). Moreover, they can be written under the form of a conventional weighted mean modified by the effects coming from the interactions between elementary performances.
More particularly, we briefly present hereafter the 2-additive CI that considers only interactions by pair[4], and that is defined by two types of parameters (Grabisch, 1997):

[4] The propositions made in this paper can be easily extended to the general case of k-additive Choquet integrals.

- the weight of each elementary performance expression in relation to all the other contributions to the overall performance evaluation by the so-called *Shapley parameters* $\nu_i\,'s$, that satisfy $\sum_{i=1}^{n} \nu_i = 1$, which is a natural condition for decision-makers,
- the *interaction parameters* I_{ij} of any pair of performance criteria, that range in [-1,1];
  - a positive I_{ij} implies that the simultaneous satisfaction of objectives o_i and o_j is significant for the aggregated performance evaluation, but a unilateral satisfaction has no effect.
  - a negative I_{ij} implies that the satisfaction of either o_i or o_j is sufficient to have a significant effect on the aggregated performance evaluation.
  - a null I_{ij} implies that no interaction exists; thus ν_i acts as the weights in a common WAM.

The associated aggregation function is thus given by:

$$p_{Ag} = \sum_{i=1}^{n} \nu_i\, p_i - \frac{1}{2}\sum_{i=1}^{n} I_{ij} \left| p_i - p_j \right| \tag{2}$$

where $\left(p_1 \ldots, p_i \ldots, p_n\right)$ is the vector of elementary expressions such that:

$$\left(\nu_i - \frac{1}{2}\sum_{j=1}^{n} \left| I_{ij} \right| \right) \geq 0, \forall\, i \in [1, n] \text{ et } j \neq i \tag{3}$$

Thus the meanings of ν_i and I_{ij} are clear, providing explanations to decision-makers on how these parameters influence the aggregated performance expressions. If these operators have more parameters than the WAM operator, their determination is based on the same principle. Evidently, more information will be required. For the sake of simplicity, we do not consider here the general case but only deal with our example.

4.3 Overall performance expression

Before computing the overall performance expression from the elementary ones, we need to determine the CI parameters, namely 4 *Shapley parameters* $\nu_i\,'s$ and 6 *interaction parameters* I_{ij}. In this sense, the decision-maker has to compare some particular situations related to the four main processes (*Plan, Source, Make, Deliver)*. These situations are known through their associated elementary performance vectors $\left(p_{Plan,}\ p_{Source}, p_{Make}, p_{Deliver}\right)$, more simply denoted $\left(p_1, p_2, p_3, p_4\right)$. In order to make such comparisons more realistic and simpler, we propose to consider fictive situations that correspond to particular cases where all the objectives are totally satisfactory, except one. The associated performance vectors will be thus: (0,0,0,1) where $p_4 = 1$ and $p_1 = p_2 = p_3 = 0$, or (1,1,0,1) where $p_1 = p_2 = p_4 = 0$ and $p_3 = 1$. Moreover, in order to identify the ten parameters of the CI, the decision-maker has thus to compare ten fictive situations under the form:

$$p_{\text{Ag}}^{(0,0,1,0)} \text{ is moderately preferred to } p_{\text{Ag}}^{(0,0,0,0)}$$

The full system, the associated matrix (Table 9) and its resolution are given in the appendix.

$$\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & -0.5 & 0 & -0.5 & 0 & -0.5 & -3 \\ 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0 & 0 & -0.5 & 0.5 & -1 \\ 0 & -1 & 0 & 1 & 0.5 & 0 & -0.5 & 0.5 & 0 & -0.5 & 0 \\ 1 & 0 & 0 & -1 & -0.5 & -0.5 & 0 & 0 & 0.5 & 0.5 & -2 \\ 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0 & 0 & 0.5 & -0.5 & -1 \\ 0 & 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0.5 & -0.5 & 0 & -4 \\ 0 & 1 & 0 & -1 & 0.5 & 0 & -0.5 & -0.5 & 0 & 0.5 & -2 \\ 1 & -1 & 0 & 0 & 0 & 0.5 & 0.5 & -0.5 & -0.5 & 0 & -4 \\ 0 & 1 & -1 & 0 & 0.5 & -0.5 & 0 & 0 & 0.5 & -0.5 & -3 \\ 0 & 0 & 1 & -1 & 0 & 0.5 & -0.5 & 0.5 & -0.5 & 0 & -3 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} v_{Pl} \\ v_{So} \\ v_{Ma} \\ v_{So} \\ I_{Pl\_So} \\ I_{Pl\_Ma} \\ I_{Pl\_De} \\ I_{So\_Ma} \\ I_{So\_De} \\ I_{Ma\_De} \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Table 9. Matrix for parameter determination

The results of the parameter determination are synthesized in the Table 10. The decision-maker can naturally correct these values, by reconsidering his judgment. We can now aggregate the elementary performances (§ 3.2.4), according to the different action plans being considered (Table 11).

v_1	v_2	v_3	v_4	I_{12}	I_{13}	I_{14}	I_{23}	I_{24}	I_{34}
12/34	9/34	7/34	6/34	5/34	3/34	4/34	5/34	0	5/34

Table 10. The Choquet Integral parameters

	p_{Plan}	p_{Source}	p_{Make}	p_{Deliver}	p_{Ag}	Interaction
ERP	0,59	0,71	0,64	0,81	0,63	0,04
EB	0,53	0,21	0,09	0,25	0,32	0,10
CMI	0,82	0,29	0,36	0,69	0,47	0,13
LCS	0,24	0,14	0,18	0,63	0,27	0,07
CBS	0,94	0,57	0,45	0,44	0,47	0,12

Table 11. The overall performance expressions associated to the different solutions

From this result, the decision-maker establishes that:

- the ERP implementation gives the best performance improvement,
- this result is nevertheless moderately satisfying because p_{Ag} is only 0.66,

- taking the interactions into account decreases the overall performance from about 5% to 25% (it is very important for the CMI and the CBS improvement projects) and can modify the ranking.
- the best performance improvement has to balance the interacted elementary performances.

More generally, the company has a systematic tool which allows not only to choose a supplier but also to diagnose the weakness of the buyer supplier relationship and to improve it. This explanation of the reasons of an unsatisfactory overall performance allows managers to adopt a more efficient improvement approach.

Note that other aspects can be handled such as the aggregated performance/investment ratio, the delay associated to the different solutions, or the critical resource utilization.

6. Conclusion and prospects

This study deals with performance measurement in a supply chain context. We have proposed in this sense a global framework to consider, understand and improve the buyer-supplier relationships. The major idea of this work is the overall performance concept. In this sense, decision-makers have one single synthetic piece of information which is, on the one hand, consistent with the new global industrial approach, and on the other hand, allows the comparison of situations conventionally considered as "incomparable". More precisely, decision-makers cannot only choose the best supplier in a given context and w.r.t the industrial projects under way, but also manage the relationship improvement, by analysing a detailed diagnosis and a quantitative evaluation of the impact of the alternative considered projects.

In the Quantitative Performance Measurement Model, the aggregation concept allows the quantification of an overall performance, in spite of the impossibility to directly measure such a performance. Moreover, the Choquet Integral (CI) operator, which takes the dependencies between criteria into account, highlights the complex relations between the elementary and the overall performance expressions, while the Weighted Arithmetic Mean (WAM) operator does not. In this sense, the MACBETH methodology has been applied to the performance quantification of the four main processes (*Plan, Source, Make and Deliver)* according to the supply chain literature. Indeed, based on human expertise, this methodology gives a structured framework, which links the elementary performance expression to the overall one.

This study will have to be completed by industrial validation. Indeed, some work is now in progress concerning the application of these ideas in some manufacturing companies, by considering moreover, the impact of the process *Return*, not handled here, on the overall performance in a buyer-supplier relationship context.

Appendix

Notation: $P_{\mathrm{Ag}}^{(0,0,1,0)}$ is the aggregated performance associated to the situation of the SC characterized by the vector of elementary performance (0,0,1,0).

$$
\left\{
\begin{array}{lll}
p_{\mathrm{Ag}}^{(0,0,1,0)} - p_{\mathrm{Ag}}^{(0,0,0,0)} = 3\alpha & = \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_Ma}} + I_{\mathrm{So\_Ma}} + I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(0,1,0,0)} - p_{\mathrm{Ag}}^{(0,0,1,0)} = \alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} - I_{\mathrm{Pl\_Ma}} + I_{\mathrm{So\_De}} - I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(0,0,0,1)} - p_{\mathrm{Ag}}^{(0,1,0,0)} = 0 & = -\nu_{\mathrm{So}} + \nu_{\mathrm{De}} - \frac{1}{2}\left[- I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,0,0,0)} - p_{\mathrm{Ag}}^{(0,0,0,1)} = 2\alpha & = \nu_{\mathrm{Pl}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} - I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(0,1,0,1)} - p_{\mathrm{Ag}}^{(0,0,1,1)} = \alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} - I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} + I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(0,1,1,0)} - p_{\mathrm{Ag}}^{(0,1,0,1)} = 4\alpha & = \nu_{\mathrm{Ma}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[I_{\mathrm{Pl\_Ma}} - I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,1,0,0)} - p_{\mathrm{Ag}}^{1,0,0,1)} = 2\alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[- I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_De}} + I_{\mathrm{So\_Ma}} - I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,0,1,1)} - p_{\mathrm{Ag}}^{(0,1,1,1)} = 4\alpha & = \nu_{\mathrm{Pl}} - \nu_{\mathrm{So}} - \frac{1}{2}\left[- I_{\mathrm{Pl\_Ma}} - I_{\mathrm{Pl\_De}} + I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,1,0,1)} - p_{\mathrm{Ag}}^{(1,0,1,1)} = 3\alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[- I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} + I_{\mathrm{Ma\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,1,1,0)} - p_{\mathrm{Ag}}^{(1,1,0,1)} = \alpha & = \nu_{\mathrm{Ma}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[- I_{\mathrm{Pl\_Ma}} + I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}} \right] \\
p_{\mathrm{Ag}}^{(1,1,1,1)} = 1 & = \nu_{\mathrm{Pl}} + \nu_{\mathrm{So}} + \nu_{\mathrm{Ma}} + \nu_{\mathrm{De}}
\end{array}
\right.
$$

The system resolution gives the following results:

$\nu_1 = 12/34$, $\nu_2 = 9/34$, $\nu_3 = 7/34$, $\nu_4 = 6/34$

$I_{12} = 5/34$, $I_{13} = 3/34$, $I_{14} = 4/34$, $I_{23} = 5/34$, $I_{24} = 0$, $I_{34} = 5/34$

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3

A Framework for Assessing and Managing Large Purchaser – Minority Supplier Relationships in Supplier Diversity Initiatives

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1. Introduction

Prior research has underscored the significance of ethnic minority businesses in socioeconomic terms, as well as the range and magnitude of barriers such businesses face (Ram & Jones, 1998; Ram & Barrett, 2000, Deakins & Freel, 2003). This stream of research highlights the pressing need for ethnic minority suppliers (EMSs) breaking out of traditional sectors of low valued added activity. Supplier diversity initiatives appear to be a potent vehicle to this end (Ram *et al*., 2002; Ram & Smallbone, 2003) [1]. Recently, private and public sector initiatives relating to supplier diversity aim to level the play field for ethnic minority firms and involve large purchasing organisations (LPOs) diversifying their supply base by purchasing from EMSs (Ram & Smallbone, 2003).
The concept of supplier diversity is gaining momentum, attracting increasingly the attention of academics, policy makers and purchasing professionals, as there are considerable benefits for LPOs (e.g. efficiency, market insight and/or innovative input) and EMSs (e.g. knowledge gains) engaging with supplier diversity (CIPS, 2005; CRE, 2006). A careful review of academic journals and textbooks reveals the paucity of research published in minority supplier diversity/development and LPO – EMS relationship domains (Giunipero 1980, 1981; Dollinger & Dailly, 1989; Dollinger *et al*., 1991; Pearson *et al*., 1993, Krause *et al*., 1999). Recently it has been suggested that supplier diversity initiatives can function as platforms for EMSs strategic learning (Theodorakopoulos *et al*., 2005; Theodorakopoulos & Ram, 2006). Nevertheless, although the scant research in supplier diversity highlights the significance of relationship factors to the success of supplier diversity/improvement programmes (e.g. Pearson *et al*., 1993), yet, purchaser-supplier relationship management as a vehicle for

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[1] Although the notion of 'diversity' is a multifaceted one, being pertinent to a host of groups that have been historically excluded and disadvantaged in some way, often including women, disable people, gays and lesbians, in this paper it relates to ethnic minority concerns. Ethnic minority businesses are organisations where the owner-manager(s) is/are of ethnic minority origin, as defined by the 2001 Census. These are typically small enterprises, employing less than 50 workers.

enhancing EMS learning and supply capabilities development has not been examined to any length within the context of supplier diversity.

Furthermore, from a LPO perspective, the increasing significance of the procurement function and decision-making underlie the need for improving the purchasing professional practice, in order to improve suppliers' learning and supply capabilities, and ultimately the LPO's competitive position. This creates an axiomatic need for instructive theory and best practice in this realm (Giannakis *et al.*, 2000). Indeed, the recognition of supply chain management as a pivotal area, both in the public and private sector has brought into sharp focus specific purchasing and supply topics. A review of the International Purchasing and Supply Evaluation and Research Association (ISPERA) conference proceedings of the last 15 years indicates the increasing interest expressed in supplier evaluation and development and, linked to these, the examination of purchaser-supplier relationships (see for instance Morlacchi *et al.*, 2002).

It has to be noted that the knowledge base built in these areas is by and large the product of research in larger purchasers and suppliers, rendering questionable its relevance and utility for small firms (Ramsay, 1994, Morrissey & Pittaway, 2006) and EMSs in particular. Thus, the aim of this chapter is to consider the characteristics of the relationship between LPOs and EMSs engaged with supplier diversity programmes that enable or constrain EMSs learning and supply capabilities development and provide a relationship assessment and management tool. The next section examines relevant literature on supply chain learning (SCL).

2. Learning at the interface of purchasing and supplying organisations

The White Paper on UK competitiveness (2000) has highlighted the ability of an organisation to learn and embed knowledge in production as pivotal to sustainable growth. Organisational growth is deemed as an outcome of organisational learning, which underlies changes in some key organisational properties, "…such as systems, structures, procedures, culture and schemata which reflect and are reflected in, changing patterns of action (routines and strategies)" (Knight, 2002, p. 432). With regard to the latter, building supply capabilities and effecting concomitant changes in products and/or processes activities[2] is reliant on institutionalising appropriate mechanisms for the capture and sharing of information and knowledge relevant to supply requirements, opportunities and competitive performance. These mechanisms are regarded as routines and are instrumental in discovering and effectively exploiting opportunities, which constitutes the essence of entrepreneurship and small business growth.

In this respect, the absorptive capacity of an organisation determines its ability to "recognize the value of new, external information, assimilate the information, and then apply the learned knowledge to its own internal product and service output" (Cohen and Levinthal, 1990, p. 128). The development of absorptive capacity is critical in the revitalisation of existing capabilities and the creation of new core competences and competitive advantages

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[2] Depending on how substantial these changes are, they can be perceived as synonymous to innovatory behaviour. The literature suggests that such changes underpin small business growth (see for instance Smallbone *et. al.*, 1995)

over time. The fact that firms operate within supply chains/networks dictates examining organisational interfaces that enable learning. In a buyer-supplier interface there is an exchange of resources, information and knowledge being among these. The relationship between a LPO and an EMS would most certainly influence the quantity and quality of information provided by the LPO, which depending on the EMS's absorptive capacity would potentially feed into the development of pertinent capabilities that match LPO's supply requirements and give rise to innovatory products and/or processes. This brings to centre stage inter-organisational relationships and attendant learning processes contributing to this end.

Yet, understanding of such inter-firm learning and knowledge development processes through which supply capabilities are generated is an issue that remains fragmented and poorly developed within the supply chain literature. Inter-organisational learning, that is learning occurring beyond the boundaries of individual organisations, has certainly received attention (e.g. Croom & Batchelor 1997, Batchelor 1998; Larsson *et al*., 1998; Dyer & Nobeoka, 2000; Croom, 2001; Bessant et. al., 2003; Bessant, 2004). Nonetheless, such research presents essential differences. Inter-organisational learning can mean learning in groups or dyads (e.g. Croom & Batchelor 1997, Batchelor 1998; Larsson *et al*., 1998; Croom, 2001) or relate to collective learning of a group of organisations belonging to a network (e.g. Dyer & Nobeoka, 2000; Knight, 2002), or even learning within a spectrum of groupings including gradations between dyad learning and network learning (Bessant *et al*., 2003; Bessant, 2004), with various levels of multi-firm arrangements.

Bessant *et al*. (2003) and Bessant (2004) discuss their experience with six SCL cases, where they examined different groupings of firms in different sectors, designed to leverage learning within given supply chain configurations. They claim that a proper SCL scheme involves a central coordinating firm, such a LPO playing an active role in assisting processes of learning amongst other firms in the value chain. In their typology of learning networks they include a 'supplier or value stream based' grouping, where the learning target relates to achieving standards of best practice in quality, delivery, cost reduction etc. Particular firms supplying to a major purchaser like a LPO is an example of this type. Their empirical evidence suggests that SCL programmes potentially enable learning at both the operational and strategic level and underlines enabling and constraining factors. Although their research does not deal with small suppliers/EMSs (at least not explicitly), their experience indicates that SCL can yield gains at both individual firm level and at the system level, as there were improvements both for the main customer and it suppliers.

This chapter deals with EMS learning taking place within the context of the purchaser-supplier dyad, i.e. between a LPO and an EMS. Two kinds of learning - adaptive and generative (Senge, 1990) - are used within a supply chain context to classify EMS's learning. When the learning outcome is straightforward, for example relatively minor adjustment of the production system to improve efficiency resulting from application of best practice, or compliance to new regulatory standards that require trivial changes in the production and/or administrative system, adaptive learning is taking place. Conversely, when the existing paradigm has to be replaced by a new one, resulting in fundamental changes in operations and/or management systems, processes or relationships, then generative learning occurs[3]. Generative learning is more difficult to achieve and is often associated with strategic learning (e.g. Chaston & Mangles, 2002). In supply chain context, process-oriented supplier change, as opposed to results-oriented change, (Hartley & Jones, 1997) may require generative learning.

Examining supplier diversity from a supply chain learning (SCL) perspective provides an opportunity for theory building that cuts across different categories, providing an integrating view of characteristics of inter-organisational relationships, in particular those between LPOs and EMSs and the effect of such relationships on EMS learning. Hence, this chapter is primarily concerned with developing a framework that could enhance understanding of EMS learning within an inter-organisational (LPO - EMS) context and be used as a relationship assessment and management tool. Focus is on the interface and the facets of relationships between LPOs and EMSs that enable or constrain EMS learning processes that underlie the creation of supply capabilities. The next section deals with characteristics that determine the potency of purchaser-supplier relationships.

3. Characteristics of the relationship between purchaser and supplier

If competitive advantage is the ultimate objective of supply chain management, then a key focal area must be the development and control of inter-organisational interactions (Hoyt & Huq, 2000; Quayle, 2000; Croom & Watt, 2000; Croom, 2001, Macpherson, 2001; Macpherson & Wilson, 2003). Indeed, research on supplier development in general and supplier diversity in particular (Pearson *et al.*, 1993) points out the significance of relationship building. Cousins (2001) propounds a two-dimensional typology of relationships based on level of certainty and level of dependency. These result in four types of inter-organisational relationships: traditional/adversarial, opportunistic behaviour, tactical and strategic collaboration. With regard to the latter, Cousins and Sperkman (2003, p.25) report that across industry sectors the main reasons for entering into collaboration are cost reduction, deliver and quality improvements, followed by supply strategies. Yet, they affirm that the true gains emanate from the flow of expertise, technology and experience "…among the supply chain partners, so that knowledge is shared, even jointly developed, thereby giving the entire supply chain a competitive advantage". They maintain that in these instances, there is a quite likely that value is brought to the marketplace that is not easily copied and is sustainable". This is plausible as inter-organisational learning processes entail a high degree of social complexity (Andersen & Christensen, 2000).

Factors moderating the relationship between purchaser and supplier include competitive pressures and priorities, resource availability, internal relationships, and purchasing and marketing abilities for buyers and suppliers respectively, degree of power and dependency (Lamming *et al.*, 1996, Forker *et al.*, 1999, Krause *et al.*, 2000). Power and dependency have a profound impact on purchaser-supplier relationships. They are determined predominantly by the size of the organisations involved, prevailing inter-industrial characteristics[4] and

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[3] The distinction between adaptive and generative learning is not always clear and depends *inter alia* on the perspective one selects, in terms of level and timescales of analysis and the pint in time the analysis takes place (see for example Knight, 2002, p.21).

[4] Although we are primarily concerned with the dyadic relationship, often firms belong to supply networks that cut across industry boundaries as buyers and suppliers may operate

institutional arrangements – although perceptions of power and dependency *per se* play a significant role (Lamming, *et al.*, 1996; Cox 2001) - and influence the relationship facets. Although EMSs/small enterprises are a key feature of almost every post-industrial economy, surprisingly, the relationship management literature has been developed by studying mainly large organisations, and there is limited research examining power and dependency from the standpoint of the EMS. However, although organisational size asymmetries and order size have a great bearing on supplier dependency within a given purchaser-supplier relationship, the type of product is a significant factor. For instance, specialised knowledge and expertise that a small supplier, operating a niche market, may possess can potentially ameliorate its position against a LPO (Lamming and Harrison, 2001). The fact still remains though that competitive power is a crucial issue when examining a LPO – small supplier (like an EMS) relationship. LPOs are in a position to use their power and make demands on performance requirements that leave the small supplier in a strenuous position (Saunders, 1997). LPOs can use the supply chain as a way of transferring costs, stocks and hence risk to smaller suppliers (Turnbull, 1991), whose workforce bear most heavily the impact of this power asymmetry (Scarbrough, 2000). Conversely, vendors particularly those facing resource constraints and being dependent on a few LPOs, like small suppliers/EMSs, have to specialise their products to the purchasers' needs (Monczka *et al.*, 1995) and forego other opportunities.

Trust, like power, is a multifaceted construct. Sako (1992) for instance distinguishes between contractual trust, goodwill trust and competence trust. It is regarded as a significant resource that grants access to information, financial and intellectual capital, support and advice and has received considerable attention form researchers of supply chain relationships. For suppliers, experiential learning through interfacing with purchasers is a crucial factor in gaining new knowledge and skills and new products and processes, as it gives access to critical routines underpinning such development activities (Croom & Batchelor, 1997; Croom, 2001). In this respect, direct involvement activities between purchasers and suppliers may provide opportunities for improving communication processes, engendering trust and creating closer, collaborative relationships (Hahn *et al.*, 1990, Langfield-Smith & Greenwood, 1998). However, the mainstream literature on power and trust fails to recognise the impact that owner-manager's motivations and behavioural characteristics may have on the relationship. Relationships are socially embedded and lifestyle goals can lead to preferences that are at odds with received wisdom (Morissey & Pittaway, 2006). As Möllering (2003, p. 38) puts it, "the more buyer-supplier relations are understood as socially embedded processes rather than in terms of a cost function, the more pressing becomes the need to move away from overly deterministic approaches". Harland *et al.* (2004) argue that "a failure to recognise the complexity and fragility of trust make direct questioning about trust an unreliable approach to research".

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in various industries and be part of different supply chains. Political, legal, economic, social and technological forces at work in these industries represent a dynamic cluster of variables that influence each other reciprocally, affecting actors and supply chains embedded in different networks. Zheng *et al*. (1998), Lamming et. al. (2000) and Harla. (2001) in their conceptual framework for the creation and operation of supply networks highlighted four contextual factors that may have a crucial bearing: market environment, product and process, network structure and focal firm network structure.

Commitment is presented as a threefold construct, including investment in the trading partner, affective commitment and the expectation of the relationship extending into the future (Kumar *et al.*, 1995). Prahinski & Benton (2004) define supplier's commitment as "the degree to which the supplier feels obligated to continue business with a particular buying firm". There appears to be an interrelation between commitment and trust, where increased levels of trust increase a firm's commitment to the relationship and *vice versa* (e.g. Kumar *et al.*, 1995; Hausman, 2001). Supplier development activities vary in terms of the level of purchasing organisation's commitment to the supplier development, from enforced competition among suppliers, to increased volume-allocation incentives, to direct involvement through training/education of supplier's personnel (Krause, 1997, Krause & Ellram, 1997a, b). Moreover, the purchaser's strategic perspective towards supplier's performance and perceptions of the supplier's commitment positively influence the purchaser's commitment to the supplier (Krause, 1999; Krause *et al.*, 2000). If supplier diversity efforts are to be successful, commitment by both purchasers and suppliers is requisite. Research on supplier diversity (Pearson *et al.*, 1993; Krause *et al.*, 1999) points out the significance of commitment to the success of EMS inclusion/improvement schemes. This requires both parties' top management support, commitment of resources, conducive intra-organisational relationships, and for LPOs a willingness to work with supplier diversity intermediaries (CIPS, 2005; CRE, 2006).

Krause & Ellram's (1997) study on success factors in supplier development reports that purchasers exhibiting a collaborative behaviour - manifested in a proactive attitude regarding suppliers' performance[5], input of resources into their supplier development efforts and a willingness to share information with their suppliers - are more likely to achieve superior results. "Formal evaluation results to the supplier, use of a supplier certification programme, site visits to the supplier, visits to the buying firm by the supplier's representatives, supplier recognition, training and education of the supplier's personnel and investment in the supplier's operation" are all contributing factors (*ibid*). The results of their study suggest that purchasing organisations may be able to improve vendors' performance considerably by expecting more from them, communicating those expectations and engaging actively in their effort. Regarding supplier selection, De Boer *et al.* (2001) after reviewing the literature on attendant decision methods conclude that research insofar has been largely concentrated on the most visible element, the choice phase, whilst the preceding phases relating to problem definition, criteria formulation and qualification have received much less attention.

Effective bilateral communication is a crucial aspect of purchaser-supplier relationships and performance (Carter & Miller, 1989; Heide & Miner, 1992; Krause, 1999; Li *et al.*, 2003, Humphreys *et al.*, 2004) that has been described as "the glue that hold together a channel of distribution" (Mohr & Nevin, 1990 in Prahinski & Benton, 2004, p. 41). Reviewing the relevant literature Prahinski and Benton (2004) state that inter-firm communication is a multifaceted concept, dimensions of which include: indirect influence strategy, content, medium, timeliness and frequency, number of buyer-supplier contacts, feedback, and formality. Timely, frequent and formal communication, with a large number of contacts between the two organisations, and an inclination to share proprietary information are all

[5] A 'proactive' attitude refers to the suppliers proclivity to anticipate and prevent supplier's capability and performance problems

characteristics fostering supplier development (Krause & Ellram, 1997). In respect of the latter, transparency in the exchange of information between purchaser and supplier is deemed as a crucial element (Lamming *et al*., 2001). In the same line, inclusive decision making and problem sharing require effective communication (Galt & Dale, 1991). This is based on trust and conversely, poor communication has been cited as a major barrier to the development of trust between the two parties and may militate against strong relationships and supplier development (Lascelelles & Dale, 1989; Landeros *et al*., 1995; Krause & Ellram, 1997; Langfield-Smith & Greenwood, 1998). Specifically in supplier diversity context, communication has been identified as a key factor by Pearson *et al*. (1993) and Krause *et al.* (1999). Communication failures may often result from lack of clear specifications from purchaser to supplier and failure to communicate dissatisfaction with the other party (Langfield-Smith & Greenwood, 1998). In that respect, the supplier evaluation communication process could be a determinant factor on a buyer-supplier relationship and supplier's commitment (Prahinski & Benton, 2004).

Sharing compatible values is crucial for successful relationships (Lambert *et al*., 1996). One of the purchaser-supplier interface pitfalls highlighted by Handfield *et al*. (2000) is poor cultural alignment. Setting expectation and communicating effectively quality criteria to the supplying firm is required in order to align their business culture. Handfield *et al*. (2000) suggest the use of a road map as a way to spur purchaser–supplier cultural alignment.

Furthermore, establishing metrics and timelines that provide a basis for follow-up and joint problem solving is critical to a thriving relationship. Heines (1996) argues that supplier coordination relates to purchaser's activities aimed at moulding their suppliers into a common way of working, in order to obtain competitive advantage, especially by eliminating inter-firm waste. Working to common quality standards, using the same paperwork system, sharing transport and using inter-firm communication platforms such as EDI are all coordinating means. Furthermore, technical and industry differences between purchaser and supplier may influence the ability to introduce new processes and practices to the latter and may affect further the willingness of the supplier's workers to accept new methods (Langfield-Smith & Greenwood, 1998). LPOs may need to modify their expectations and conversely EMSs may need to consider whether they need to adjust their own position to accommodate LPO's requests that could strengthen their relationship.

Moreover, closely linked to examining inter-firm relationships is the assessment of eight networking activities 'partner selection', 'resource integration', information processing', knowledge capture', 'social co-ordination', 'risk and benefit sharing', decision making', 'conflict resolution'(Zheng *et al*., 1998; Lamming *et al*., 2000; Johnsen *et al*. 2000; Harland *et al*., 2001) and 'motivation' (Harland *et al*., 2004). There is considerable correspondence between the relationship characteristics discussed above, and the content of these network activities. Harland *et al*. (2001) submit four distinct categories of supply networks, based on two dimensions; the degree of supply network dynamics and the degree of focal firm supply network interference. They argue that the challenge for managers is to identify which type of supply network they are in and apply networking activities accordingly.

In the light of the above, the strategic merits of closer inter-organisational relationships, the ability to build such relationships and the impact of relational capabilities on product and process capabilities take centre stage in supply chain management. Hence, if small firms and EMSs in particular are to supply LPOs, they have to develop relational capabilities that enable the improvement of product/process capabilities. Studies in the manufacturing sector support this contention (Croom, 2001; Macpherson 2001; Macpherson & Wilson, 2003). However, on this point Prahinski & Benton (2004) note that commitment is a key facet, as cooperative efforts from the purchaser's side, aiming at strengthening the inter-firm relationship, do not necessarily translate to supplier's improved performance, unless the supplier is earnestly committed. Table 1 below refers to requisite relational and process/product supply capabilities.

Capabilities	Indicative types
Relational Capabilities	Commitment Communication Cooperation Problem-solving Attitudinal Flexibility Cultural empathy
Process Capabilities	Benchmarking Technological Continuous improvement Process Flexibility - Process Innovativeness
Good/Service Capabilities for existing/new products	Quality Speed Dependability Flexibility Cost

Source: Adapted from Macpherson and Wilson, 2003

Table 1. Required Supplier Capabilities

In respect of capabilities, Hahn *et al*. (1990) provide a different categorisation, as to product and process capabilities (they do not address the relational set). The extent to which a supplier development/supplier diversity programme contains clear-cut phases - where each phase aims at developing a different set of capabilities - is largely determined by the level of development and sophistication found in the industrial sectors in question. In Hahn *et al*.'s (1990) study, the American firms did not have to go through the formal stages of supplier development. Their industries were well developed and the initial supplier selection process had already eliminated most of the poor suppliers. The next section sets out a conceptual framework which can be used as a relationship assessment tool to examine and manage the conduciveness of the LPO-EMS relationship to EMS learning and supply capabilities development.

4. Developing a relationship assessment and management framework

The above discussion on interaction factors affecting the purchaser-supplier relationship highlights key influencers that have to be considered in building a conceptual framework. This would provide crucial issues for investigation in a systematic way and constitute a relationship assessment and management tool. An array of relationship models that have been developed insofar was examined. Among these, Lamming *et al.*'s (1996) RAP model for assessing relationships between purchasers and suppliers stands out. The barycentre of their analysis and discussion is the dyadic relationship, as a separate entity, where the state of these relationship facets is a product of the buyer-supplier dynamic interaction. Their model has been influential in that it brings in sharp focus the purchaser-supplier inter-organisational relationship characteristics, providing a systematic way to examine the relationship context within which EMS learning takes place.

However, Lamming *et al.*'s (1996) work is designed to assess the compatibility between the assessment criteria used by the purchasing organisation and the development stage of the relationship. Although they acknowledge that "intra-company development should be combined with inter-company development" to improve competitiveness (p. 176), their conception does not address how inter-organisational relationship facets underpin the supplier's learning processes and - development of subsequent - dynamic capabilities. Figure 1 illustrates our partial, tentative conceptualisation of the factors impacting on the LPO – EMS relationship and points out some of the key relationship facets that require development and active management in order to foster EMS learning and supply capabilities development.

We have altered substantially their model in terms of content and configuration of constructs. The enablers mediating constructs *Resource Commitment* and *Contact Frequency Type* are now part of our 'Relationship Facets' category as *Commitment* and *Communication* respectively, which characterise a given relationship. In accordance with Harland *et al.* (2004) we believe that assigning causation and denoting antecedent constructs is problematic, as for instance *Contact Frequency and Type* could be both an antecedent and outcome of *Problem Solving*. On these grounds we eschew illustrating monocausal relationships.

Also, the constructs *Closeness* and *Relationship Depth* have been omitted and instead we introduce the constructs *Trust*, *Commitment*, *Communication*, *Cooperation*, *Coordination*, *Cultural Alignment* and *Risk and Benefits* as relationship facets, which emanate from our foregoing discussion and cover aspects of the original constructs *Closeness* and *Relationship Depth*. These are situated within the shaded central elliptical area, bounded by the intermittent line. They are all mutually influencing, moderated by *Power* and *Dependency*, which are included in the outer elliptical area, but also affected by, and to some extent impinge on, the preliminary influencing factors *Competitive Priorities, Internal Relationships, Available Resources, Order Size and Type,* and buyer's *'Purchasing Abilities'* and supplier's '*Marketing Abilities*', which are posited within the rectangular domains to the left and right of the elliptical areas. This schema has to be viewed in light of the external operating environment, both the immediate micro (competitors, customers, suppliers etc.) and remote (political, economic, technological and legal) impacting forces.

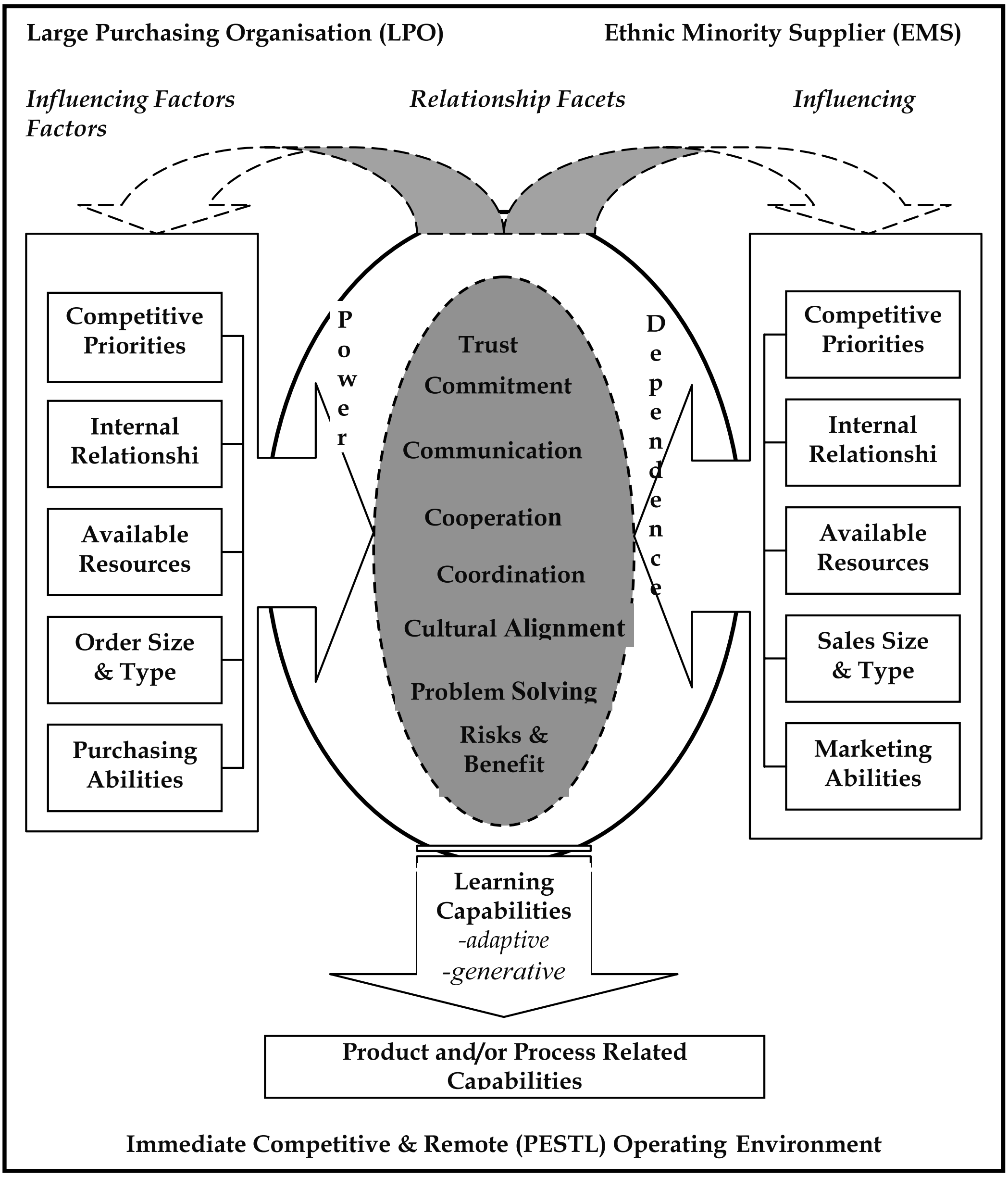

Figure 1. LPO-EMS Relationship Assessment & Management Framework (©Theodorakopoulos & Ram, 2007)

Logic suggests that the higher the *Commitment*, the more intensive the *Communication* efforts, the higher the level of *Cooperation,* the greater the degree of *Cultural Alignment*, the more complete the engagement in *Problem Solving*, the greater the *Sharing of Risks and Benefits* between the parts involved in the dyadic relationship, i.e. the LPO and the EMS, the stronger their relationship. A strong relationship then is achieved by focusing on and managing these facets. Conceivably, an assessment of their relationship should consider the nature and form of these factors, and their interrelation. Following from this a strong relationship between a LPO and an EMS require relational capabilities that address the aforementioned relationship facets, which underpin EMS learning capabilities, which in turn influence positively the development of supply capabilities, requisite for performance and competitiveness enhancement. Given that EMSs are predominantly fairly small firms, usually with limited resources and product mix, considering the LPO-EMS relationship in a relatively unitary sense does not disregard the caveats expressed by Harland *et al*. (2004) against viewing dyadic relationships as singular and uniform.

We propound that the relational capability of managing these facets constitutes a dynamic capability (Hamel & Prahalad, 1994) in its own right for both the LPO and the EMS, as it enables the latter to learn and develop process and product supply capabilities, which in turn enhance the innovativeness and competitiveness of both parties. We argue that this tentative conceptualisation retains the flexibility of allowing for consideration of a number of possible relationship types within variant sectors and enables a comparison of perception of relationship strength by LPOs and EMSs by providing a structured frame of reference, animating discussion and research. While the submitted framework is perhaps more suitable for assessing established purchaser-supplier relationships, it could be useful for pointing out, and alerting both parties – LPOs and EMSs - to issues that have a profound impact on the development of their relationship and arguably merit a proactive stance, depending always on the level of collaboration pursued by both parties.

5. Avenues for operationalisation

While much of the published research considers inter-firm relationships from the purchaser's perspective, there is a need to consider important issues in the development of these relationships from both the supplier and the buyer perspective (Langfield-Smith & Greenwood, 1998) and examine their impact on supplier's capability building and innovative behaviour. Prahinski & Benton (2004) argue that there are no studies that have examined the supplier's perspective of the purchasing firm's communication on supplier's performance. Perhaps Dunn & Young's (2004) study constitutes a bright exception. Indeed, there is a need for research that examines the intensity, duration, frequency and effectiveness of the various supplier development strategies, their impact on the relationship between purchaser and supplier and related benefits. In the same vein, there is a need to look at both sides of the purchaser-supplier dyad in order to provide balance and insight into how suppliers perceive supplier diversity and development. As Forker *et al*. (1999) maintain, checks on perceptual congruence between purchasers and vendors will help either revisiting an ineffective programme or enhancing understanding of an effective one, with positive impact on their relationship. Focus should be on how effective LPOs' communication efforts are, how much effort they actually devote to supplier diversity/development, and whether the LPOs' efforts to increase the EMSs' supply capabilities and performance constitute an enabling factor or a hindrance from the EMSs' perspective. On these grounds, a longitudinal study that examines the effects of supplier diversity/development efforts on the purchaser-supplier relationship and performance would be worthwhile (Krause, 1997, Krause & Ellram, 1997, Krause *et al*., 2000). Dunn & Young's (2004) study does not deal with minority suppliers but is a step in this direction. The fact that we are specifically dealing with EMSs renders this argument more compelling, as there is a pressing need to better understand the processes underlying relational and supply capabilities and assist EMSs breakout to mainstream markets.

A significant problem militating against a cohesive body of knowledge is that even prior studies that are not concerned specifically with EMSs are based on empirical research which addresses the theme of inter-organisational relationships only partially. Harland *et al*. (2004, p.220) note that "purchasing studies tend to be based in the manufacturing sector, and the majority of service management and marketing studies focus on relations within individual consumers…The former tend to neglect service-based relations, the latter tend to neglect business-to-business relations and both have yet to address adequately supply to the public sector". This is reminiscent of De Boer *et al*. (2001) contention that most of the literature on purchasing decision methods lies within the manufacturing ambit. It is noteworthy that Krause & Scannel's (2002) findings indicate that service firms tend to rely on the competitive pressure of market forces to instigate supplier performance to a greater extent than goods-based businesses, which tend to use assessment, incentives and direct involvement to a greater extent than service firms. Given the importance of the service sector, research that deals with the specifics of decision methods in service supplier selection and development within a supplier diversity context would be worthwhile.

Moreover, in congruence with Harland *et al*. (2004), De Boer *et al*. (2001) identify Government procurement as a particularly interesting area for researching the suitability of decision methods for supplier selection, given the necessity to warrant public purchasing decisions and the attendant European Union regulations. Ram & Smallbone (2003) argue that there are ways to assist EMSs to access public sector contracts, without infringing EU rules. This is an area that certainly requires attention from practitioners, researchers and policy makers. While there is evidence that some local authorities acknowledge the supplier diversity concept as 'good practice' (Ram & Smallbone, 2001) the experience of pioneer initiatives such as the Haringey Council and West Midlands SME procurement pilots indicate considerable challenges (OGC, 2005). Thus, applying the relationship assessment and management framework illustrated in Figure 1 in situations where the LPO is public sector organisation appears a promising avenue of research.

Finally, much of the research effort in supply chain relationships focuses on successful ones and best practices rather than average or failed relationships. Yet, as Harland *et al*. (2004) affirm, studying negative occurrences provides the opportunity to learn from mistakes. Hence, while it is important to examine the applicability of the framework in contexts of successful LPO-EMS relationships, we also need to consider how well it holds in 'negative' instances.

6. Conclusion

Supplier diversity initiatives can function as platforms for EMSs strategic learning (Theodorakopoulos *et al*., 2005; Theodorakopoulos & Ram, 2006) and the scant research in supplier diversity underscores the importance of relationship factors to the success of supplier diversity/development programmes (e.g. Pearson *et al*., 1993). However, purchaser-supplier relationship management as a vehicle for enhancing EMSs learning and supply capabilities has not been examined to any length within the context of supplier diversity.

Hence, the aim of this chapter was to consider the characteristics of the relationship between LPO and EMS that enable or constrain such learning. Our emerging tentative conceptualisation holds that the development of supplier diversity programmes can potentially cultivate a relationship between LPO and EMS, which influences positively the latter's learning, often involving knowledge transfer from the LPO to the EMS. This in turn has a positive effect on the development of EMS supply capabilities and the enhancement of both parties' competitiveness. The proffered relationship assessment and management framework portrayed in Figure 1 brings in sharp focus the characteristics of the relationship between LPO and EMS, providing a systematic way to examine the inter-organisational context within which EMS learning takes place. We purport that the relational capability of managing these facets constitutes a dynamic capability (Hamel and Prahalad, 1994) in its own right for both the LPO and the EMS, as it enables the latter to learn and develop process and product supply capabilities, which in turn enhance the innovativeness and competitiveness of both parties.

Finally, the relationship assessment and management framework submitted could signpost future research, policy making and practice in this domain. Given the paucity of research in supplier diversity, examining the learning potency of LPOs-EMSs relationships by applying the proffered framework can help both parties engaging with supplier diversity to develop fruitful relationships that enhance their competitiveness. With regard to future research avenues, a multiple-case study focusing on LPOs-EMSs dyadic relationships, cutting across different sectors and considering both purchasers' and suppliers' perspectives would be apropos. Moreover, a longitudinal, processual dimension is necessary to provide opportunities to examine the dynamics underlying the development of potent inter-firm relationships in a variety of settings, including negative instances. Important issues for investigation relate to LPOs purchasing and EMSs supplying paradigms, policies and practices that influence positively and negatively the relationship facets displayed in the framework and in turn the effect of these characteristics on EMSs learning, supply capabilities development and overall competitiveness.

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4

An Evaluation Framework for Supply Chains Based on Corporate Culture Compatibility

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1. Introduction

To date research focused on the role corporate culture plays when planning a supply chain management system (SCMS) has been limited. Although many executives have recognize the importance of corporate culture (e.g., Hollingsworth, 1988), research however, has only begun to review the role corporate culture plays on planning information systems to avoid cultural conflicts (Leidner & Kayworth, 2006). Therefore, without a sound understanding of the corporate culture compatibility that influence organization behaviour it will be difficult to successfully plan SCMS initiatives. The purpose of this research is to develop an initial framework based upon the SCMS planning and culture literature to identify the needs for cultural compatibility that impact planning of SCMSs.

The fundamental premise of this research is that the literature supports the view that an organization must establish a corporate culture understanding to achieve an effective performance and competitive advantage inside the organization (Chan, Shaffer, Snape, 2004) and within the boundaries of a supply chain (Mentzer et al., 2001) prior to successfully planning SCMSs. The role of corporate culture can become especially critical at the boundary-spanning level of the organization, where organizations systems interface with other members of the supply chain. Accordingly, when supply chain's organizations collaborate under cultural compatibility environment, the SCMS is more likely to be executed in a uniform and effective manner (Mentzer et al., 2001). Nevertheless, recent frameworks of SCM planning ignore the role corporate culture plays to achieve an effective collaborative performance.

In the next section we give a short review of supply chain planning and management philosophy. This is followed by a theoretical investigation of the problem by reviewing the limitation in the current supply chain models. We then outline the significance of corporate culture compatibility to improve supply chain planning and achieve the ultimate SCM performance. This outline proposes the need for a new framework that is defined in the followed section. Finally, an agent-based simulation model concerning a three-level supply chain is described. This developed model integrates the proposed framework of cultural learning to evaluate the SCM performance. The results are, then discussed and significant outcomes are outlined.

2. Supply chain planning framework

Miller (2001) presents a three level general framework for the hierarchical supply chain planning that spans the strategic, tactical, and the operational planning levels. Figure 1 presents Miller (2001) hierarchical supply chain planning framework.

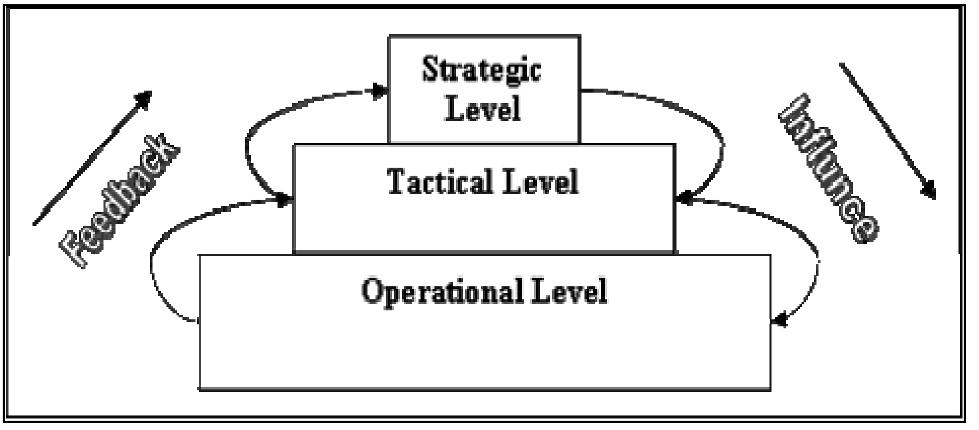

Figure 1. Miller's Hierarchical Supply Chain Framework

At the strategic level the supply chain organizations must address its overall corporate objectives, which include market share, profitability goals, production capacity, facilities to operate and its locations, the required resources and other crucial long-term decisions for the coming three to five years in future (Miller, 2001). Decisions made on the strategic level will often impact the decisions at the tactical level (miller, 2001). Therefore, the tactical level has decisions with more details about the planning activities. For example, organizations at this level allocate the production capacity and available resources to production lines, and decide about the inventory management plan. Therefore, the plans at the tactical level is not long term plans, rather it is a mid-term plans for the next twelve to eighteenth months. In a similar way to the strategic level, the decisions outcomes at the tactical level influence the decision-making process at the operational level, because it might add some constraints on the organization's operations. Furthermore, decisions at the operational level often involve weekly or at most monthly planning activities like forecasting the products stock keeping unit level, or the production schedule. Nevertheless, the operational level is the base level where infeasibilities of higher levels plans are revealed, because what might appear to be feasible at the strategic level or tactical level may contains infeasibilities at lower level. Therefore, Miller's hierarchical supply chain planning framework suggested feedback loops from operational level to tactical level and from tactical level to strategic level subsequently. Nevertheless, as supply chain members move through a closed loop process whereby they identify their strategic, tactical, and operational planning activities. This closed loop process involves an *influence* and *feedback* processes to enhance the supply chain plans, thus this closed loop is called "*Supply Chain Evolution*" (Miller, 2001).

3. Current supply chain management planning model

In order to model Miller's framework (2001), a number of agent-based model's approaches has been suggested. Several authors propose agents to simulate the supply chain management system planning, for example Fan et al., (2003) provide a theoretical design that could plan the supply chain activities at the operational level, while HinKKanen et al., (1997) focus on optimization of resource allocation within a manufacturing plant at the tactical level. A rule-based approach has been proposed by Fox et al., (2000) which is concentrate on coordination problem at both the tactical and the operational levels. Furthermore et al., (2000) performed preliminary researches to design an agent-based model to optimize the collaborative inventory management. Moreover et al., (1998) designed an agent-based approach to simulate the dynamics in supply chains and the control variables at the strategic level as well.

We may conclude that current simulation approaches lack some modeling capabilities that are required for successful supply chain simulation, because it cannot handle the computational complexity of supply chains. In reality supply chain organizations require to achieve a compatibility level of corporate culture prior to commence their operations (McAfee et al., 2002). Mostly, previous models facilities strongly focus on the operational and tactical levels with few others at the strategic levels, leaving the planning at the organization's cultural level implicit. As net result corporate culture compatibility is often ignored because it is hidden, intangible, or the analyst's choice is to build a visualized model and corporate culture is too difficult to capture.

Nevertheless, we argue that the aforementioned agent-based model must recognise a moral issue about these planning activities; (ii) make some kind of moral judgement about that issue; (iii) establish a belief system to act upon that judgement; and (iv) finally, actually act according to their beliefs. Therefore, there is influence on the supply chain planning decision process that is associated with *cultural* factors, such as socialization processes, which shape what is regarded as right and wrong in a given organisational situation. There is considerable evidence to suggest that cultural factors understanding have a considerable impact on the supply chain planning decision making (Cooper & Ellram, 1993; Lasser et al., 1995; Cooper et al., 1997; Mentezer et al., 2001; McAfee et al., 2002; Min et al., 2004).

However, to date there has been little research investigating how exactly these factors interact together to shape a common understanding of corporate culture between all supply chain organizations. Such needs for cultural sensitivity and meaning drive a need to add a cultural level to the hierarchical supply chain planning framework that must involve the individual understanding of the organization's corporate culture to achieve a common understanding (or compatibility) of corporate culture between all organizations. Hence, we need a new framework that proposes an organization's cultural level together with the strategic, tactical and operational levels.

4. Significance of corporate culture compatibility to supply chains

Prior to discuss the crucial role that corporate culture compatibility play we will firstly define the concept "corporate culture". The succinct definition will then followed by theoretical proofs from the literature about the significance of corporate culture compatibility to sustain effective supply chain relationships between partners.

4.1 Corporate culture definition

A basic definition of corporate culture is necessary to provide a point of departure in the quest for an understanding of the phenomenon. Deal & Kennedy (1982, p.23) state that "*shared values [that] define the fundamental character of the organization, the attitude that distinguishes it from others…create sense of identity for the organization [and these] values are a reality in minds of most people throughout the [organization]*". In other words, corporate culture includes those qualities of the organization that give it a particular identity, climate or feel. As a result the distinct qualities of an organization may manifest through four dimensions, namely the tough-guy/macho culture, the work-hard/play-hard culture, the bet-your company culture and the process culture (Deal & Kennedy, 1982). Schein (1985, p 9) defines corporate culture as "*a pattern of basic assumptions invented, discovered, or developed by a given group as it learns to cope with its problems of external adaptation and internal integration that has worked well enough to be considered valid, and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems*". This description highlights that corporate culture is created assumptions, which are accepted as a way of doing things and are passed on to new members of an organisation. Nevertheless, the main source of corporate culture is the organisation's leadership. Leadership in this context refers to the influential individuals, often the founders who have a major impact on the creation of the organisation's early culture (Schein, 1985). However, this pattern of values, norms, beliefs, attitudes, principles and assumptions may be unwritten or non-verbalised behaviour that describe the way in which things get done; to give the organisation its unique character (Brown, 1998). In other words, corporate culture includes those qualities of the organisation that give it a particular identity, climate or feel. Martins & Martins (2003, p 380) state the general definition of corporate culture as "a system of shared meaning held by members, distinguishing the organisation from other organisations". Furthermore, Arnold (2005, p 625) indicates that "*[corporate] culture is the distinctive norms, beliefs, principles and ways of behaving that combine to give each organisation its distinct character*". These definitions present corporate culture as a distinct factor that identifies an organization from other organizations.

4.2 Corporate culture significance to supply chain systems

When supply chain management system (SCMS) projects experience significant configuration problems, several researchers argue that the existence lack of cultural compatibility (sometimes called alignment) between the supply chain organizations' corporate culture is a major contributing factor (Hollingsworth, 1988), because corporate culture is a pre-requisite for a successful collaboration business (Gardner & Copper, 1988). Cooper & Ellram (1993) consider corporate culture compatibility as a key characteristic that distinguishes SCMSs from other short-term collaborative systems, because corporate culture compatibility are less important for short-term relationships that for long-term. Cooper and Ellram (1993), however, highlighted that Incompatibility on corporate culture may exits between certain supply chain members, but this often challenges the long-term relationship between partners. Culture compatibility on SCMSs dose not assume similarities on operating strategies, procedures and agreement on every issues, but it simply implies a harmony on the essential directions to sustain an effective collaborative relationships (Cooper & Ellram, 1993; Bucklin & Sengupta, 1993). Initial research has shown that many organizations consider corporate culture compatibility to be the most-important evaluation criterion they used to measure the collaboration successfulness (Lasser et al., 1995), and a "bridge-building" when individual organizations decide to move from a stand alone toward a collaborative business as supply chains (Cooper et al., 1997). Recent studies, in addition, introduce "*supply chain orientation*" as a new term that "*defines the organization capability to recognize the strategic implications and tactical activities utilized to facilitate the various flows in a supply chain*" (Mentzer et al., 2001). Mentzer et. al. (2001) and his colleagues define corporate culture compatibility in a supply chain as a mean of achieving a supply chain orientation by all supply chain members.

5. Definition of the new framework

The foundation of this framework comes up from our deep literature review of corporate culture and in particular the process of changing corporate culture. Brown (1998) identified the needs for pre-selection step prior to change corporate culture. This step *explores* the space for new changes on cultural values amongst the supply chain organizations. Afterwards & Brown (1998) culture change process *evaluates* the opportunities to integrate the new corporate culture changes with the current culture. Furthermore, the changing process of corporate culture performs an influencing step throughout a socialization process, to *embed* the new produced corporate culture changes into the new and current supply chain members. Therefore, to learn about changes on corporate culture an organization must go through these three stages of *exploring, evaluating, and embedding* corporate culture.

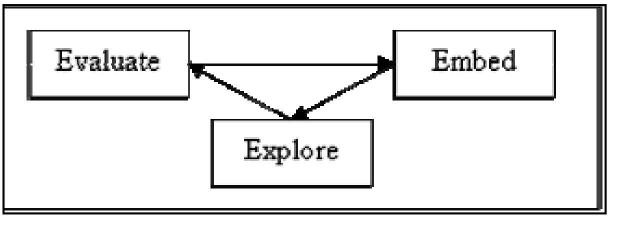

Figure 2. The Corporate Culture Learning Framework

5.1 Constitutes of the framework

The learning framework of corporate culture in figure 2 contains three interrelated processes Exploration, Evaluation, and Embedding. The framework processes form the glue that binds the structure together, there are, therefore three key facets of the framework. The first process of the framework begins with an Exploration process to search for the corporate culture changes. This process needs to check for possible culture changing patterns between supply chain organizations. The corporate culture is, for example, represented by management practices and strategies, what behaviour is rewarded, condemned or ignored (e.g. risk taking, training and helping new employee, applying regulations), and how an organization values their people (e.g. the best is the most creative, the ordered, or the supportive people). The second process of the framework is the Evaluation process. In this stage the organizations start evaluating the outcomes of the exploration process to validate its appropriateness to the current corporate culture. The Embedding process attempts to integrate the evaluated new corporate culture and influence current and new organization's members and partners about the required changes on corporate culture to increase their gains and improve the organizational performance. Thus, future members of the organization's system can benefit from these experiences associated with any corporate culture changes. Therefore, this theoretical learning framework sustains a continuous improvement to the strategic relationships amongst the organization's members and partners, and concurrently evolves the internal beliefs of this organization. The framework learning process occurs over an evolution path that possesses a feedback process represented by the Evaluation step and an influence process represented by the Embedding step. Therefore, the framework can easily integrated to Miller's framework with Evaluation step and Embedding step correspond to feedback process and influence process respectively (see figure 3).

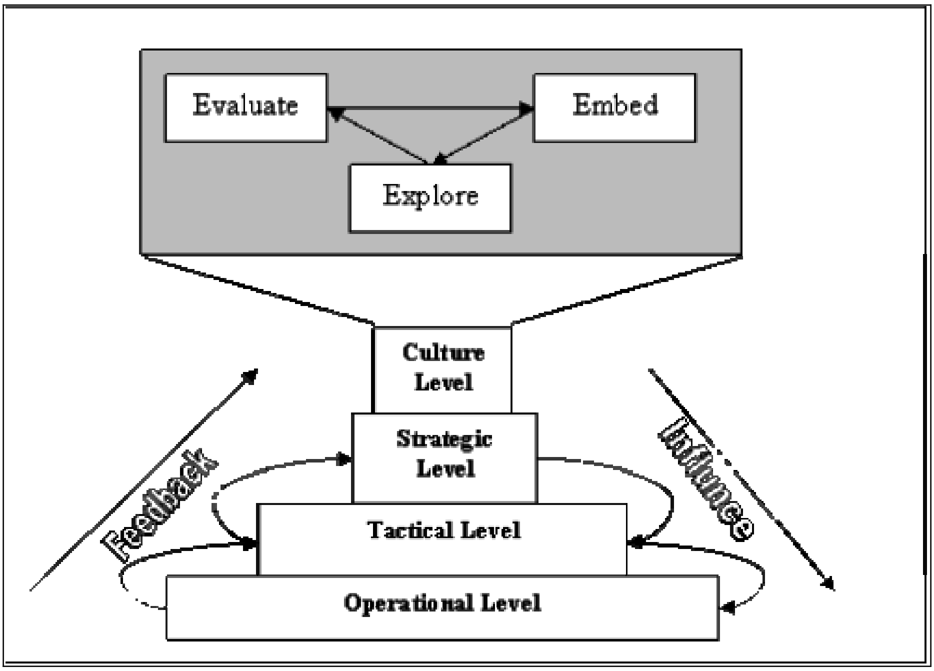

Figure 3. The Supply Chain Management Planning Framework

5.2 Modeling the new framework

We model the framework by using the Gaia methodology for agent-based model analysis and design proposed by Zambonelli et al., (2003). The agents' model describes the different agent classes based on their roles. However, the designer might choose to package closely related roles in a single agent class to optimize the design or attain more design coherence by utilizing a one-to-one strategy and map each single role to an agent class.

The agent model of Gaia can be defined using a simple annotation class from (Zambonelli et al., 2003). An annotating (n) means that there will be exactly (n) agents of this agent's class in the run-time model. An annotation (m...n) means that there will be no less than (m) and more than (n) instances of this class in a run-time model. An annotation (*) means that there will be zero or more instances at run-time, and (+) means that there will be one or more instances at run-time. The notation to reference the agent class model is as follow:

$$Agent\ Class^{(annotation)} \xrightarrow{play} (Role\ Name)^{+}$$

Hence, the agent model for this research is the following:

$$Embed\ \ Agent^{(1)} \xrightarrow{play} Embedding$$

$$Explorer\ Agent^{(1)} \xrightarrow{play} Exploring$$

$$Evaluator\ \ Agent^{(1)} \xrightarrow{play} Evaluating$$

5.3 Internal structure

Elaborating on the agent model definitions supplied in the previous section, in this section we will consider the internal structure of agents.

Explorer Agent: The explorer agent adopts the cultural dimension from Deal & Kenndy (1982) described before. Therefore, the agent speculates the behaviour of supply chain agents based on four attributes associated with the organization corporate culture. These attributes are:

- Low Risk taking: this strategy is applied when the organization is not willing to take a high risk by, for example, decreasing its investment and spending to reduce it potential lost.
- High Risk taking: this strategy is applied when the organization is willing to take a high risk by increasing its investment and boosting the spending to promote its products.
- Quick Feedback; this strategy is applied when the organization is seeking a very quick response from its participants and meeting the schedule is a crucial objective for this strategy.
- Slow feedback: this strategy is applied when the organization is expecting a regular response time from its participants and meeting the schedule is not the highest priority objective.

These attributes form a common corporate culture structure, but a loosely coupled with each supply chain agent has the capability to adjust its individual belief's contents. Therefore, for each instantiated corporate culture the value of these cultural attributes are:

- Zero which indicates that the attribute is insignificant for the organization,
- Or, one to indicate that the organization has a belief to this attribute.

Evaluator Agent: The Evaluator agent's main objective is to evaluate the collected results after the exploration process undertaken. Therefore we developed an evaluation function to measure the fitness of each individual understanding of corporate culture. The f(A) is an evaluation function such that it expresses the proposition of all relevant and available evidence that support the claim that supply chain members who possess the individual understanding of organization's corporate culture that support the corporate culture A but to no particular subset of A. The f(A) is valued by the ratio of supply chain members holding the same corporate culture, thus f(A)is a value between zero and one inclusive.

$$f(A) = \frac{\sum\limits_{i=0,\ Culture(i)-A=\varnothing}^{N} SupplyChainMember(i)}{\sum\limits_{i=0}^{N} SupplyChainMember(i)} \tag{1}$$

Embed Agent: The Influencer Agent in the simulation is modelled using Roulette wheel selection technique to distribute the shared understanding of corporate culture according to their calculated fitness in equation (1). The influencer Agent has a fitness function that assigns fitness value to current shared understanding of corporate culture. This fitness level is used to associate a probability of selection with each shared understanding of culture. While candidate solutions with a higher fitness will be less likely to be eliminated, there is still a chance that they may be. With fitness proportionate selection there is a chance some weaker solutions may survive the selection process; this is an advantage, as though a solution may be weak, it may include some component which could prove useful following the recombination process. Therefore, the Influencer agent's main objective is to embed new shared understanding of corporate culture on next supply chain generations to achieve more corporate culture compatibility.

6. Experimentations and evaluation of the framework

We developed a supply chain simulation environment to simulate and encompass the challenges involved when trying to achieve corporate culture compatibility, yet, by keeping the rules simple, to ensure a competitive, stimulating and learning environment.

6.1 The developed simulation model

Fundamentally, the main feature of the simulation environment (table 1) involves different supply chain's organizations with dissimilar individual understanding of corporate culture whose aim is to assemble three different Televisions set, and subsequently compete against each other for customer orders, then acquire the orders and deliver the various products to the customers. The products built for customers are TVs assembled from five component types. The supply chain's organizations must respond to the customer's request for quotes giving the price of the products plus a delivery date in order to allow the customer to select the best offer. When delivery of the goods has been met wholly and adequately by the due date, then the Customer places the payment in the bank, where each supply chain organization has an access to its bank account. However, failing to deliver the products timely and adequately will incur delay penalties on the organizations' accounts. There are limitations imposed upon the organizations to make its role more difficult and to incorporate an incentive challenge. Each simulated day the retailers' are competing to acquire as many as possible customer orders, however the retailer not only has to win customer orders, and respond to demands for different types of TVs, but also must be aware that each TV type requires different combinations of components and an assemble cycles (see table 2).

Parameters	**Limitations**
Manufacturing Capacity	500 assembly cycles/day
Supplying Capacity	500 Components/day
Retailers Delivery Capacity	500 Products/day
Delay Penalties	10% of the customer reserve price

Table 1. Simulation Environment Limitations

Therefore a retailer must establish relationships with manufacturers and suppliers. Nonetheless, all organizations must work within the capacity parameters as seen in the table above. A key issue is that the five types of components represented: Chassis, Picture Tube, Speaker, Power Supply, and Electronics all have a variety of categories, so the products are customizable (see table 3). As well as the practical limitations, the organizations must face the challenge of competing concurrently within the markets for products, for customers and for the different components produced by several suppliers. Therefore, successful organizations need to show the ability to respond rapidly and using a skilled strategy, react positively to the varieties of demand by the customer, yet, as well, sustaining better relationships with participants. The organizations should be able to perform these tasks, whilst adequately balancing the interdependencies, and, be able to act even if having only incomplete information about other organizations' corporate culture. To juxtapose such tasks successfully is demanding, yet the supply chain organizations also need to have the additional ability to adapt to the corporate culture employed by other competing and collaborating organizations, and indeed, even attempting to outwit them. The simulated demands are representative of a broad range of supply chain situations and should, therefore, offer the competing organizations an authentic challenge.

TV Types	Components	Assembly Cycles
Low-TV-1	100+(200/210)+(300/310)+400+500	3
Low-TV-2	110+(201/211)+(300/310)+(400/410)+501	3
Med-TV-1	101+(200/210)+(300/310)+410+501	4
Med-TV-2	111+(201/211)+(300/310)+(400/410)+500	4
High-TV-1	101+(200/210)+(301/311)+400+500	5
High-TV-2	111+(201/211)+(301/311)+400+501	5

Table 2. TVs Description

Component ID	Supplier	Description
100	S1	Flip Chassis
101	S1	Sany Chassis
110	S2	Sopra Chassis
111	S2	Amcor Chassis
200	S3	Sany Picture Tube
201	S3	Sonic Picture Tube
210	S3	ViewSus Picture Tube
211	S3	GL Picture Tube
300	S4	Taship Speaker
301	S4	PH Speaker
310	S4	Creator Speaker
311	S4	Blaster Speaker
400	S1	WD Power Supply
401	S2	Limited Power Supply
500	S3	Panason Electronics
501	S4	Sany Electronics

Table 3. BOM of all TVs types

According to the aforementioned simulation environment and for the purpose of this study, we have developed a three sub-chain simulation model as shown in Figure-4.

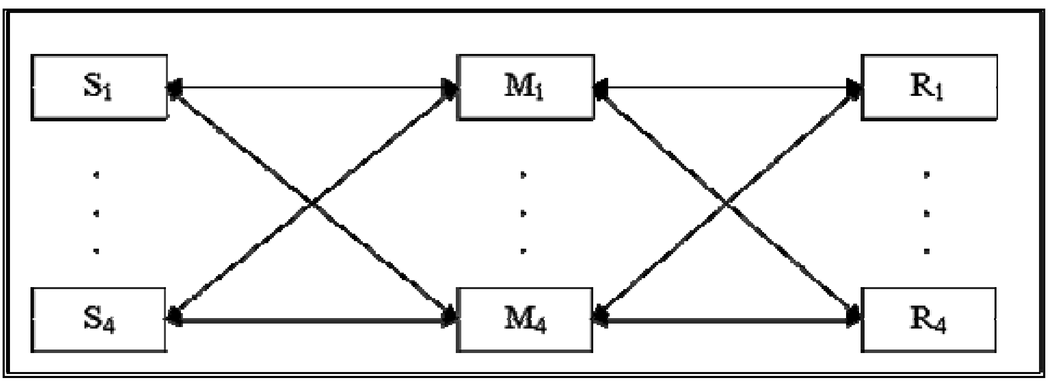

Figure 3. Three-levels supply chain model

To develop the simulation model we have utilized the RePast toolkit[1]. The RePast system is a Java-based toolkit for the development of lightweight agents and agent models. The model comprises of 4 manufacturers connected to 4 retailers and 4 suppliers. The manufacturers accept orders from retailers and request bids from suppliers indicating the product type and quantity for the required materials from suppliers. A Supplier, then either sends its quotation to manufacturers or a regret message if requests cannot be fulfilled. Based on the

[1] http://repast.sourceforge.net/

received quotation manufacturers select the most appropriate suppliers based on the minimum orders waiting time and issues the orders. Upon receiving the required materials from suppliers, the manufacturers initiate necessary actions to make the products and ship it to retailers. Furthermore, retailers will perform business with the manufacturer and will deliver the required products with the minimum waiting time to avoid incurring delay penalties. Hence, the time elapsed between the placements of an order and the receipt of products is measured as supply chain's lead-time performance.

We have added a culture component to facilitate the links between sub-chains according to the level of Culture compatibility between partners. We have suggested that corporate culture compatibility may be seen as a means towards greater organizations synchronization. Corporate culture compatibility offers alternatives that can lead to changes in the management practices, procedures and policies that subsequently can impact the flow of entities in a direction that may result in an improved supply chain model. The entities may consist of products, customer orders, information, decision and resources etc. Moreover, we have proposed four Culture types where we have assumed that Culture Type 1 is the Macho Culture, while Culture Type 2, 3, 4 represent Work-Hard culture, Bet-Your-Company Culture and process culture respectively. However, each culture type is allocated with a value that defines the time needed to perform supply chain activities under this culture type as shown in table 4.

Culture Name	Macho	Work Hard	Bet-Your-Company	Process
Culture's Strategy	High Rish and Quick feedback	Low risk and Quick feedback	High risk and Slow feedback	Low risk and Slow feedback
Culture Type	Type C_1	Type C_2	Type C_3	Type C_4
Value	-2	-1	1	2

Table 4. Culture Types Values

Therefore if two organizations have implemented the same culture by operating the same business strategy then both are performing the activities at the same time, whereas if culture type is different then there is a waiting time for one organization. Therefore the equation to calculate the lead-time performance becomes the following:

$$\sum C_i = |C_S - C_R| + |C_M - C_R| + |C_S - C_M| \tag{2}$$

Where, C_i is the aggregate culture value for all organizations type

$$\text{Lead-Time} = \sum C_i + \text{Supplier(Time)} + \text{Manufacturer(Time)} + \text{Retailer(time)} \tag{3}$$

6.2 Framework evaluation

The focus during these simulation experiments was to figure out the quality of the framework, measured in terms of Lead-Time performance, varied with the increases of shared understanding of corporate culture. We therefore, run the experiments with two groups of supply chain organizations: group A and group B. Group A has a link with the proposed framework agents, thus their individual understanding of corporate culture is influenced by the shared understanding of corporate culture. On the other hand, group B has no link with the proposed learning framework agents and subsequently the organizations receive no influence on their individual corporate culture.

We found that both groups commence the simulation with well performance because both groups start with adequate resources to accept customer orders. Next when customers' orders increases and resources begin to decrease as organizations utilize it, group B starts to behave inefficiently because they do not have adequate resources. Moreover the new generations on group B will inherent the individual corporate culture understanding from previous generations which make their performance somewhat stable with no significant improvements. Therefore, each organization attempts to satisfy his own needs. Group A, however, behaved inefficiently in the beginning, because each organization resisted changing of individual understanding of organization's corporate culture. Nevertheless, after a number of generations, the new organizations in group A start adapting their individual corporate culture understanding to align with the shared understanding of corporate culture and turn their behaviour back to more efficient performance. On the other hand, group B may reach a close result, but the organizations need more time to recover without shared understanding of corporate culture.

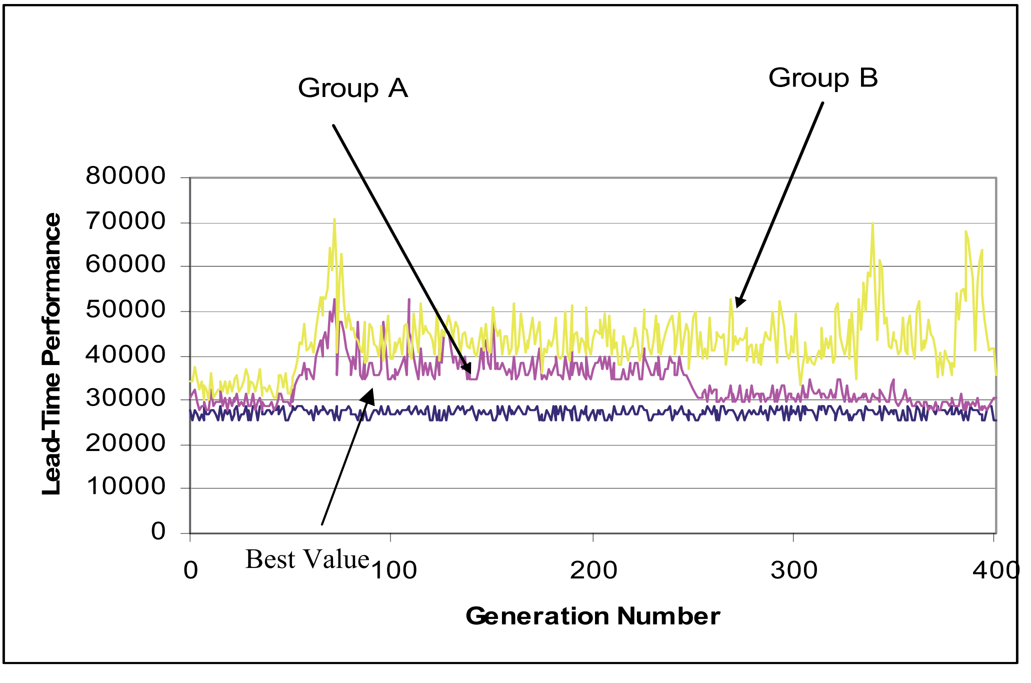

Figure 4. A comparison between Group A and Group B organizations

7. Conclusion

We have presented a framework to evaluate the lead-performance of the supply chain management based on the corporate culture compatibility system. The goal is to implement a supply chain simulation model that has the capability to measure the corporate culture compatibility of supply chain organizations to achieve an effective supply chain performance. We also described the first step towards this goal in the form of a simulation study to support our proposition. Therefore, we modelled the proposed framework as a multi-agent system.

In the near future we plan to integrate the current version of the multi-agent model of the simulation with other supply chain agent based models. According to the literature, corporate culture is defined with different views, therefore we would like to be able to measure the corporate culture of individual supply chain organization and aggregate them to form a compatible corporate culture for the entire supply chain. Furthermore, we plan to study how we can aggregate different views of corporate culture in the existence views diversity of individual organization's culture.

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5

How Negotiation Influences the Effective Adoption of the Revenue Sharing Contract: A Multi-Agent Systems Approach

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1. Introduction

Supply Chain Management (SCM) can be pursued by adopting a centralized or decentralized control. In the former case, a unique decision maker exists in the SC, who possesses any information on the whole SC that is relevant to make decision and the contractual power to have such decisions be implemented. The centralized control assures the system efficiency (channel coordination). In the case of decentralized control, different decision makers exist in the supply chain (SC), who pursue their own objectives, which can be conflicting and lead to system inefficiency. To cope with this problem, proper coordination mechanisms need to be adopted, which modify the incentives of the different decision makers, so as to induce them to maximize the SC total profit.

SC contracts are coordination mechanisms that utilize incentives to make SC actors' decisions coherent among each other. In particular, the incentives let the risk and the revenue (which arise from different sources of uncertainty and from channel coordination, respectively) be shared by all SC actors.

SC contracts allow two main objectives to be achieved: i) to increase the total SC profit so as to make it closer to the profit resulting from a centralized control (channel coordination) and ii) to share the risks among the SC partners (Tsay *et al.*, 1999)

A further important issue for the contract design concerns the so-called *win-win* condition: this occurs if under the contract every SC actor gains a profit higher than he/she would get without contract. Otherwise, the SC actor would not be prompted to adopt the contract.

Different models of SC contracts have been developed in the literature. They include the quantity flexibility contracts (Tsay, 1999), the backup agreements (Eppen & Iyer, 1997), the buy back or return policies (Emmons & Gilbert, 1998), the incentive mechanisms (Lee & Whang, 1999), the revenue sharing contracts (Cachon & Lariviere, 2000; Giannoccaro & Pontrandolfo, 2003), the allocation rules (Cachon & Lariviere, 1999), and the quantity discounts (Weng, 1995).

Most of these models address the problem of coordinating serial SCs made up of two stages. Moreover, the majority of them addresses channel coordination, whereas much less emphasis is given to the analysis of the conditions supporting the contract implementation. In fact, even if an effective contract exists, this does not imply that the SC agents will adopt it. They need to reach an agreement on the values of the contract parameters, given that they influence their profit. As a result, every SC actor will tend to impose her own preferences that could not be accepted by the others.

We focuses on the implementation issues of SC contracts. In particular, we consider the revenue sharing contract. As pointed out by Cachon & Lariviere (2002), a few problems can limit the use of revenue sharing contracts, namely the amount of administration costs due to the contract implementation, and the retailer efforts on sales. In fact, once a contract is designed, its implementation is not always straightforward. Organizational problems, such as those related to the parties' relative contractual power as well as the need for sharing certain information among parties, may indeed lessen the potential benefits coming from adopting a contract. Therefore, adequate attention should be paid to (i) designing the contract so as to make it acceptable by the parties and (ii) analyzing the process by which the parties reach the agreement on the contract.

Our aim is to characterize the scenarios that are appropriate for the adoption of the revenue sharing (RS) contract. First we identify the main features characterizing the video-rental industry (such as the distribution of contractual power among the actors and the shape of the supply chains involving them) in which the RS contract is already effectively used, and compare such features with other industries not adopting the contract. Then, we develop a simulation analysis to define the scenarios in which the RS is more likely to be successfully implemented.

Simulation is carried out through an approach based on agent-based systems (Ferber, 1999; Durfee, 1998; Wooldridge, 2000). Such systems consist of a set of autonomous agents (each modeling a certain SC actor), which share their information and cooperate each other to achieve a global goal while optimizing their own objectives.

Recently, the agent-based systems have been used to address SCM issues. For example, Lin & Shaw (1998) propose a multi agent information system approach for the re-engineering of the order fulfilment process in a SC. Cantamessa (1997) reviews the seminal works on agent-based modelling applied to address manufacturing issues and proposes a generic agent-based simulator useful to build agent-based models in manufacturing domain. Similarly, but with more attention for SCM applications, Swaminathan et al. (1998) propose a multi-agent simulation-based framework for developing customized SCM models from a library of software components involving generic SCM processes and activities. Albino et al., (2006) develop an agent model to study cooperation and competition in the SCs of an industrial district.

The agent-based systems approach is chosen as it allows us to model the cooperative and competitive behaviors of the different SC actors (that independently make decision, coherently with a decentralized control) and the strategies they adopt to negotiate.

Each agent is provided by objectives, beliefs, and actions. They negotiate seeking to reach an agreement on the values of the contract parameters. At the end of negotiation, however, the SC agents could adopt or not the RS contract due to the beliefs influencing their behaviors. In this way the scenarios which favor the implementation of the RS contract can be identified.

The chapter is organized as follows. First, we introduce the RS contract and the main features of the industries in which it is used. Then, we design a RS contract for a two-stage SC that assures the channel coordination and satisfy the *win-win* condition. Successively, we develop the agent-based system model of the negotiation process. Finally, the simulation analysis is carried out and the results are presented.

2. The revenue sharing contract

The RS contract is a coordination mechanism offered by the distributor to the retailer, which modifies the retailer's profit (as well as the distributor's) so as to incentive her to make decision coherent with the SC total optimization. A RS contract is described by two parameters (ω, Φ): the supplier charges the retailer the unit wholesale price ω, lower than the unit marginal cost c, in exchange for the percentage (1-Φ) of the retailer's revenue. The condition $\omega < c$ guarantees channel coordination, whereas Φ determines the distribution of total profits between supplier and retailer. In particular, Φ is the SC profit quota gained by the retailer (Cachon, 2004).
The RS contract is widespread mostly in the video-rental industry and has been adopted by companies such as Blockbuster Inc. and Holliwood Entertainment. The specific features of this industry that can be identified as favorable to the application of the RS contract are listed in Table 1.

Demand uncertainty (that can be stochastic and variable)
Single selling period
Single type of retailers
Goods supplied by unique supplier
Competition among retailers
Not satisfied inventory and demand are lost
Demand not influenced by sales promotions made by retailers
Easy control on retailer profits by the distributors

Table 1. Features of video-rental industry important for application of RS contract

Based on such features, we argue that a few other industries not yet adopting the RS contract are potential user of the RS contracts: CD, editing, newspaper, flowers.

2.1 The design of the revenue sharing contract for a two-stage supply chain

In this Section we present a revenue sharing (RS) contract and point out the way in which it can assures both *effectiveness* and *desirability*. The RS model is said to be *effective* (first objective) if it assures channel coordination, while it is said to be *desirable* (second objective), if all the chain partners increase their profits (with respect to the market setting) by adopting the contract. Notice that desirability is key if the bargaining power is symmetrically distributed among the chain partners, whereas it is less relevant if one or a few partners can make the others accept an uneven sharing of the (increase of the) total profit.
Consider a SC in which a distributor D provides a single product to a retailer R, who in turn serves the market demand. The demand is uncertain, with probability density function $f_d(d)$. The marginal unit costs of the retailer and distributor are c_1 and c_2, respectively. The distributor charges the retailer a wholesale unit price ω. The retailer sells the product at the unit price p (Figure 1).

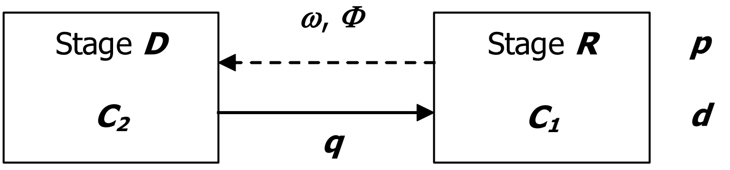


Figure 1. The two-stage SC model

The SC is characterized by a decentralized control, namely each SC actor makes decision by optimizing his own objective. In particular, the distributor D chooses the wholesale unit price ω, whereas the retailer decides the order quantity q, each of them trying to maximize his own profit. Both actors are risk neutral.
To achieve channel coordination (effectiveness), the two independent decision-makers should act coherently so as to maximize the SC total profit given by:

$$\Pi(q) = R(q) - q \cdot (c_1+c_2) \tag{3.1}$$

being $R(q)$ the expected retailer's revenue during the selling period.
Under the RS contract, the retailer's profit is given by:

$$\Pi_R(q) = \Phi \cdot R(q) - q \cdot (\omega + c_1) \tag{3.2}$$

Therefore, the retailer's optimal quantity q^o must satisfy:

$$\Phi \cdot R'(q^{\circ}) = \omega + c_1 \tag{3.3}$$

Hence, to achieve channel coordination, it is necessary that the optimal order quantity chosen by the retailer (q_h) corresponds to the order quantity that optimizes the SC total profit (q^c).
The latter satisfies:

$$R'(q^c) = c_2 + c_1 \tag{3.4}$$

By matching the (3.3) with the (3.4), it follows that, under the RS contract, the distributor will set a wholesale unit price such that:

$$\omega = \Phi \cdot (c_1 + c_2) - c_1 \tag{3.5}$$

Given that ω must be positive, it follows that:

$$\Phi > c_1/(c_1+c_2) = \Phi_{min,cc} \tag{3.6}$$

To assure desirability, the contract has to be designed so that every SC actor achieves a profit higher than he/she would do without contract. Otherwise, the SC actor would not be prompted to adopt the contract. We measure such a desirability for actor X by the expected value of the ratio Π_{Xc}/Π_{Xm} between his profits with and without (i.e. under a market-like setting) the contract. The higher the ratio (provided that it is not lower than 1), the more actor X is content with the adopted contract. To measure such a desirability index it should be known the unit price applied by every actor to his customer under a market-like setting (Giannoccaro & Pontrandolfo, 2004).
The values of Φ that assure desirability as stated above can be derived by letting all the expected value (E) of the ratio Π_{Xc}/Π_{Xm} be not lower than 1 for each $X \in \{R, D\}$.

The profits of retailer under the contract and the market-like setting are respectively:

$$\Pi_{Rc} = \Phi \cdot p \cdot \min\{q,d\}-(\omega+c_1)q \tag{3.7}$$

$$\Pi_{Rm} = p \cdot \min\{q,d\}-(\omega_m+c_1)q \tag{3.8}$$

where ω_m is the market price.
The profits of distributor under the contract and the market-like setting are respectively:

$$\Pi_{Dc} = (1-\Phi)p \cdot \min\{q,d\}+(\omega - c_2)q \tag{3.9}$$

$$\Pi_{Dm} = (\omega_m - c_2)q \tag{3.10}$$

By substituting equations (3.7) to (3.10) into the two *win-win* conditions ($\Pi_{Xc}/\Pi_{Xm}>1$) and being ω given by the (3.5), it follows:

$$\Phi > [p \cdot \mathrm{E}(\min\{q_m,d\})-(\omega_m+c_1)q_m]/[p \cdot \mathrm{E}(\min\{q^c,d\})-(c_1 + c_2)q_c] = \Phi_{min,ww} \tag{3.11}$$

$$\Phi < 1-[(\omega_m - c_2)q_m)]/[(p \cdot \mathrm{E}(\min\{q_c,d\})-(c_1 + c_2)q_c] = \Phi_{max} \tag{3.12}$$

Therefore, any RS contract, which is both effective and desirable, has to simultaneously satisfy the inequalities (3.6), (3.11), and (3.12), which results in $\Phi \in \{\Phi_{min};\Phi_{max}\}$, being $\Phi_{min} = max\{\Phi_{min,cc}, \Phi_{min,ww}\}$.
Notice that Φ affects how the SC profit is shared between the retailer and distributor. This issue is directly related to the contract implementation process: in such a process the distribution of the contractual power play a key role in determining the actual Φ value. Therefore, we explicitly model contractual power in next Section.

3. The model of the negotiation process

In this Section we model the negotiation process between the distribution and the retailer, to analyze whether and how they reach an agreement on the Φ value.
We assume that the negotiation process is affected by two main variables, namely the relative contractual power of the SC actors and the collaboration among them.
The relative contractual power has been described in the literature in terms of abandon of the negotiation process by the actor: the most powerful actor will tend to devote lesser time to negotiate and will tend to more frequently threaten the abandon of the negotiation. In this way, the most powerful actor influences the negotiation process so as to reach a more advantageous agreement (Grant, 1999).
In particular, we use the following two variables to operationalize the contractual power of the SC actor: (1) the propensity to negotiate, and (2) the propensity to threaten the abandon of the negotiation. We assume that if the contractual power is high then the propensity to negotiate is low and the propensity to threaten the abandon of the negotiation is high.
The above variables model the competitive behavior of the parties. However, the latter can show a cooperative behavior as well. Relationships based on collaboration between buyers and suppliers characterize indeed the most recent trends in supply management. In this case the SC actors tend to become partners sharing costs and rewards (Lamming, 1993; Bensaou, 1999). Therefore, when the two actors are collaborative, they will behave so as to reach an agreement that satisfy both of them. We then consider the propensity to collaborate of the SC actors as a further variable of the model.

3.1 The Agent-based model of the negotiation process

Let us consider the SC described in Figure 1. The two SC actors are the agents of the model. The two agents intend to adopt the revenue sharing contract (ω,Φ) to achieve channel coordination. To do this and increase their profits, they need to reach an agreement on the value of $\Phi \in [\Phi_{min}; \Phi_{max}]$.

Therefore the retailer and the distributor negotiate the Φ value. We assume a discrete time negotiation process made up of K steps. Each step (k) of the negotiation process starts with a bid of the distributor that offers a given value of Φ ($\Phi_D(k)$), followed by the answer of the retailer. Notice that the first bid of the distributor is equal to Φ_{min}, whereas the most advantageous value of Φ for the retailer is Φ_{max}.

According to the most common agent architecture (Wooldridge, 2000), the agents are defined in terms of objectives, beliefs, and actions. In particular, the beliefs defines the agent mental model that drives its behaviour. Behavioural rules defining the agent behaviour are built using beliefs and actions, namely the values of the beliefs influence the action the agent undertakes.

The objective of each agent is to maximize his own profit.

Based on the above discussion, the beliefs of the agent are:

- Propensity to negotiate, namely the probability that the agent will negotiate at a given step (Pr_n);
- Propensity to threaten the abandon of the negotiation (Pr_t), namely the probability that the agent will threaten the abandon of the negotiation at a given step;
- Propensity to collaborate, namely the variation of Φ ($\Delta\Phi$) that the agent is willing to offer at the next step. Notice that this is positive for the distributor and negative for the retailer.

We assumed the first two beliefs as dynamic (i.e. they change according to the trends shown in Figure 2, with K =10). The last belief is assumed to be constant.

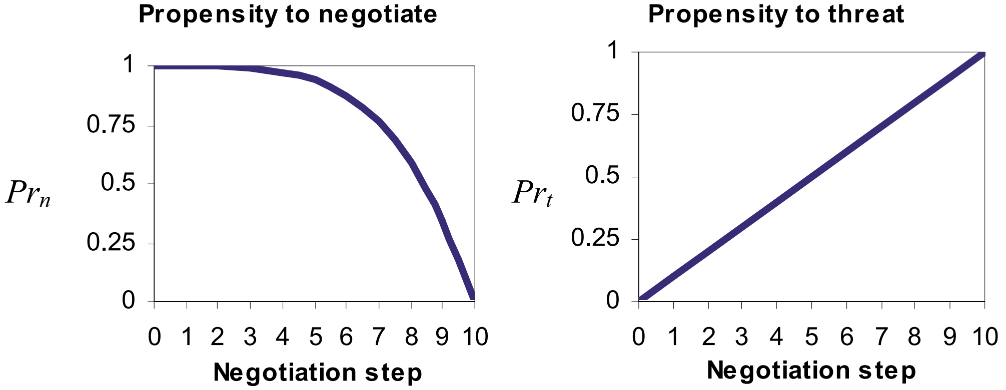


Figure 2. The agent dynamics beliefs.

At a given step of the negotiation, each agent is characterized by the values of propensity to negotiate and propensity to threaten the abandon of negotiation. These values represent the probability that in step k the agent will negotiate ($Pr_n(k)$) and will threaten the abandon of the negotiation ($Pr_t(k)$), respectively.

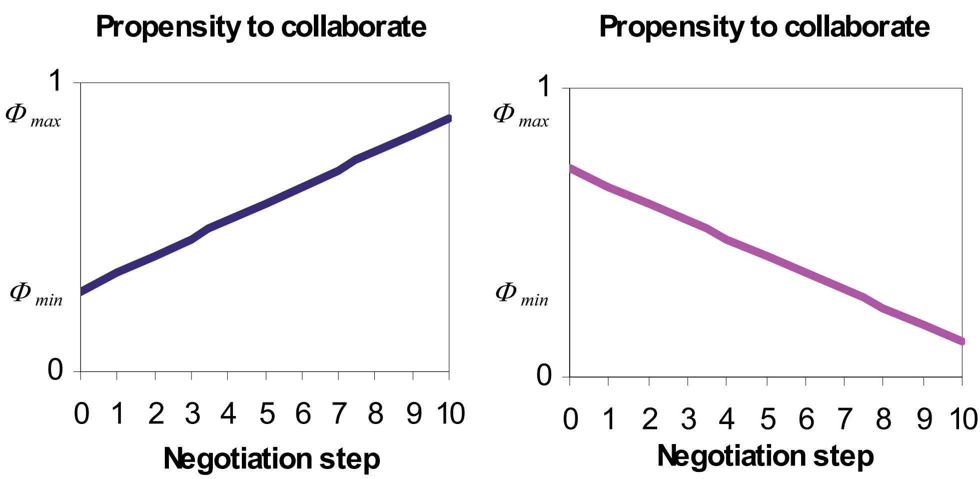
All the beliefs influence the choice of the actions undertaken and the Φ value offered at each step by the agent.

The agent has **four** alternative **actions** to be chosen:

– "To accept the bid";
– "To not accept the bid and to make a new bid";
– "To exit the negotiation";
– "To threaten the abandon of the negotiation".

At each step a random number $x \in (0,1)$ is drawn lots. If x is lower than $Pr_n(k)$, the agent will accept the bid. On the contrary, if x is higher than $Pr_n(k)$, the agent will randomly choose between two actions, i.e. "to not accept the bid and to make a new bid" and "to exit the negotiation". In the first case, there is also the possibility to threaten the abandon of the negotiation. As before, a random number is drawn lots. Only if the latter is lower than $Pr_t(k)$, the agent will threaten the abandon of the negotiation. In this case, the other agent has only two alternative "to accept" or to "exit the negotiation". The choice between these two actions is random.

The value of Φ that is offered by the agent at each step depends on the propensity to collaborate. At a given step the agent will offer a value $\Phi(k) = \Phi(k\text{-}1) + \Delta\Phi$ (Figure 3).



Distributor Retailer

Figure 3. The choice of Φ during the negotiation

The negotiation process can end in two ways: 1) the agents reach an agreement on the value of Φ (*agreed* Φ), and 2) the agents do not reach an agreement.

Our aim is to analyze how the relative contractual power of SC actors and the collaboration among them influence the RS contract adoption, in terms of the actual use of the RS contract and the value of the agreed Φ.

4. Simulation analysis and results

We conducted a simulation analysis using the proposed model (the assumed cost and demand data are reported in Table 2). The simulation is developed by using MatLab.

SC Variables	c1	c2	ωm	P	D
Value	1	2	18	30	Normal distribution, mean = 100, std. dev. = 30

Table 2. Cost and demand data.

We simulated different scenarios characterized by diverse behaviors of the retailer and the distributor due to the values assumed by their beliefs, i.e. propensity to negotiate (Pr_n), propensity to threaten the abandon of the negotiation (Pr_t), and propensity to collaborate ($\Delta\Phi$). In particular, each variable can assume two values, namely *High* and *Low*. Figure 4 depicts the data assumed for the propensity to negotiate and the propensity to collaborate in both cases. $\Delta\Phi$ is assumed equal to 0.1 (*high*) and 0.05 (*low*).

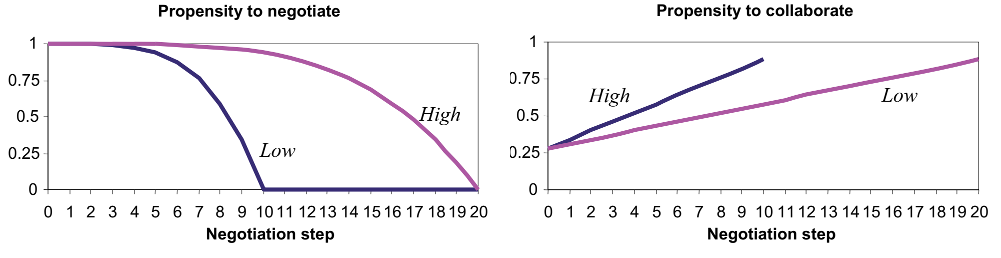


Figure 4. Data assumed for the agent beliefs

In each scenario we carried out 1000 runs and measured: the number of times that an agreement is reached on Φ ($\%RS$ is the relative frequency of agreement) and the average value of *agreed* Φ ($Av\Phi$). Then, we computed the SC profit, which depends on both $\%RS$ and $Av\Phi$: we assumed that the actors achieve the profits associated with the contract with probability $\%RS$ and the profits associated with the market setting with probability (1-$\%RS$). The SC profits are then given by:

$$\Pi_{SC} = \Pi_R + \Pi_D$$

$$\Pi_{R(D)} = \%RS\,\Pi_{R(D)c} + (1-\%RS)\,\Pi_{R(D)c}$$

Results of the simulation analysis are shown in Table 3.

In Table 4, only the SC profit are reported. Notice that the worst SC profits are achieved when the contractual power is *low* for both SC agents (fourth column), no matter the propensity to collaborate. In such a case, none of the actors is able to impose his/her preference and the negotiation tends to end more frequently without an agreement. Only a *high* propensity to collaborate by the retailer can slightly improve the SC profit under this contractual power setting.

Relative contractual power		**Propensity to collaborate**		$Av\Phi$	$\%RS$	Π_{SC}	Π_R	Π_D
Distributor	Retailer	Distributor	Retailer					
High	High	Low	Low	0.366697	58.90%	2353.584	786.064	1567.52
High	High	High	Low	0.368474	66.00%	2384.233	813.5713	1570.662
High	High	Low	High	0.365149	66.30%	2385.529	809.0421	1576.486
High	High	High	High	0.36616	73.00%	2414.452	833.8039	1580.648
Low	High	Low	Low	0.359251	60.10%	2358.764	778.885	1579.879
Low	High	High	Low	0.360741	64.10%	2376.031	794.3732	1581.658
Low	High	Low	High	0.362365	59.40%	2355.742	781.2793	1574.463
Low	High	High	High	0.354521	69.60%	2399.774	801.5961	1598.178
High	Low	Low	Low	0.37171	61.10%	2363.081	801.4199	1561.661
High	Low	High	Low	0.37279	58.10%	2350.13	792.2589	1557.871
High	Low	Low	High	0.37223	58.80%	2353.152	793.9527	1559.199
High	Low	High	High	0.37048	67.90%	2392.436	823.6709	1568.765
Low	Low	Low	Low	0.37006	55.40%	2338.474	778.6829	1559.792
Low	Low	High	Low	0.37154	53.80%	2331.567	775.0321	1556.535
Low	Low	Low	High	0.36048	62.00%	2366.966	787.0223	1579.944
Low	Low	High	High	0.37016	58.10%	2350.13	788.3914	1561.739

Table 3. Results

		Contractual Power								
Propensity to collaborate		D	R	D	R	D	R	D	R	Average
D	R	H	H	H	L	L	H	L	L	
H	H	2414.45		2392.44		2399.77		2350.13		2389.20
H	L	2384.23		2350.13		2376.03		2331.57		2360.49
L	H	2353.58		2363.08		2358.76		2338.47		2365.35
L	L	2384.45		2364.70		2372.58		2346.78		2353.48
Average		2384.45		2364.70		2372.58		2346.78		

Table 4. SC profits

Also, the results are quite poor when the propensity to collaborate is *low* for both agents (fourth row), regardless the contractual power. In this case the agents are not able to reach an agreement on the value of Φ, given that they tend to modify their initial preference at a lower rate (low $\Delta\Phi$).

Leaving out these worst cases (last column and row), the best SC profits are achieved when both agents are highly propense to collaborate (first row). In fact, in this case the agreement is reached with a higher frequency, given that both the agents modify the Φ value with a higher pace (higher $\Delta\Phi$). Only when both agents have low contractual power (last column), a high propensity to collaborate of both is not enough to guarantee an adequate percentage of agreement: this could depends on the sensible reduction of those agreements wherein the negotiation ends because one of the parties forces the other to accept his bid. This seems to be confirmed by the good results achieved when both agents have *high* contractual power (first column): the high quota of "forced" agreements compensate the possible lower propensity to collaborate.

Notice that the best scenario, characterized by high contractual power and propensity to collaborate for both agents, is associated with the highest number of agreements (73%).

82In this case even though the value of the average Φ is not the highest (which would let think the retailer to miss his highest possible profit), the retailer gains the highest profit, due to a higher number of agreements. Furthermore, also the distributor achieves a good performance (i.e. the best third one of its results).

5. Conclusions

The revenue sharing contract is a coordination mechanism adopted by supply chains, wherein the decision making process is decentralized, to assure channel coordination. It has been mainly used in the video-rental industry by firms such as Blockbuster or Hollywood Planet. Despite the ease of this coordination mechanism, based on two parameters, the RS contract is not much widespread in other industries due to implementation problems. We have then analyzed this issue.

First, we have defined the features of the video rental industry which we believe critical with respect to the RS contract adoption. This has allowed other industries to be identified as potential users of the contract. Then, we have described the design of a RS contract for a two-stage SC that assures the channel coordination and allows the SC actors to increase their profits.

Successively, we have developed an agent-based system model of the negotiation process between the two SC actors which takes into account two further variables, which we believe to play a key role for the negotiation: the relative contractual power and the collaboration of the SC actors.

In the proposed model, the two agents (i.e. the SC actors) negotiate on the value of the contract parameter that influences the SC profit sharing between them. Based on the agent beliefs influencing their behaviors, the negotiation process can end in different ways: either the agents reach an agreement on the value of the parameter, or they can not reach such an agreement (which results in the SC not adopting the contract and operating under a market setting).

Finally, we have carried out a simulation analysis aimed at identifying the scenarios in which the RS is more likely to be adopted. In particular, we have measured how many times the negotiation ends with an agreement and the agreed value of the parameter.
The simulation has shown that high propensity to collaborate for both SC actors and high contractual power of al least one SC actor prove critical for the RS implementation. In this case only the collaboration of retailer can increase the SC profit. Further research will be devoted to extend the model to different SC topologies (e.g. SCs made up of one distributor and multiple retailers).

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6

Mean-Variance Analysis of Supply Chain Contracts

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1. Introduction

According to the Council of Supply Chain Management Professionals (September 2007), we have the following description for supply chain management:
"*supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies*." From this description, it is obviously true that a supply chain in general has multiple channel members (usually called stages) and the coordination and collaboration among these members is a crucial task in supply chain management.
In the literature, various policies for supply chain optimization and channel coordination have been proposed. Among them, setting a supply chain contract between individual parties has received much attention in recent years (Tsay et al. 1999, Cachon 2003). Contracts such as buy-back contract, revenue sharing contract, quantity flexibility contract and rebates contract are all known forms of contract which can help to achieve channel coordination in a supply chain. However, in the majority of the literature works, the channels' and supply chain's objectives are either maximizing the expected profit or minimizing the expected cost. There is no discussion on the level of risk associated with these contracts. As a result, the contract parameters under which coordination is achieved may be viewed as unrealistic by decision makers. In light of this, we conduct in this paper a mean-variance analysis on some popular forms of supply chain contracts such as buy-back contract. By including a constraint on profit uncertainty, we illustrate how decision makers can make a scientifically sound and tailored decision with respect to their degrees of risk aversion. Managerial implications are discussed.
The organization of the rest of this chapter is as follows: We briefly review some related literature in Section 2, the discussion of the supply chain's structure is presented in Section 3. The mean-variance analyses on the buy-back contract and wholesale pricing profit sharing contract are conducted in Sections 4 and 5, respectively. We conclude with some discussions on managerial implications in Section 6.
For a notational purpose, we use the following notation in many places throughout this chapter: P = profit, EP = expected profit, SP = standard deviation of profit, MV = mean-

variance. The subscripts "*M*, *R*, *SC*" represent "Manufacturer, Retailer, Supply Chain", respectively.

2. Literature review

Pioneered by Nobel laureate Harry Markowitz in the 1950s, the mean-variance formulation has become a fundamental theory for risk management in finance (Markowitz 1959). In decision sciences, the mean-variance approach and the von Neumann-Morgenstern utility approach (called utility function approach in short) are two well established methodologies for studying decision making problems with risk concerns. The utility function approach is more precise but its application is limited owing to the difficulty in getting a closed form expression of the utility function for every individual decision maker in practice. The mean-variance approach, as what Van Mieghem (2003) mentioned, aims at providing an implementable, useful but approximate solution. It is true that a utility function in general cannot be expressed fully in terms of mean and variance only. However, it is shown in Van Mieghem (2003) that maximizing a utility function with a constant coefficient of risk aversion is equivalent to maximizing a mean-variance performance measure (also see Luenberger 1998, Choi et al. 2008 for some supplementary discussions). There are also evidences in the literature which demonstrate that the mean-variance approach yields a solution which is close to the optimal solution under the utility function approach (see Levy & Markowitz 1979, Kroll et al. 1984, and Van Mieghem 2003). Moreover, some meaningful and applicable objectives, such as the safety first objective (Roy 1952), can be formulated under the mean-variance framework. Despite all kinds of arguments on the mean-variance approach, it is adopted as the performance measure in this chapter because it's "applicable, intuitive and implementable". In addition, more analytical results can be generated under this approach. On the other hand, even though the mean-variance and utility function approaches are well-established in finance, their applications in supply chain management are not yet fully revealed. In fact, most research works on this important topic appear only in recent years. We review some of them as follows.

First, in Lau (1980), instead of maximizing the expected profit, the author derives an optimal order quantity which maximizes an objective function of the expected profit and standard deviation of profit for the classic newsvendor problem. Next, Eechhoudt et al. (1995) study the classic newsvendor problem with risk averse newsvendor via a utility function approach and obtain some interesting findings on the optimal stocking quantity. Later on, Lau and Lau (1999) directly extend the work of Pasternack (1985) and study a single-manufacturer single-retailer supply chain model under which both the retailer and manufacturer seek to maximize a linear objective function of the expected profit and variance of profit. Choi et al. (2008) analyze via a mean-variance approach the supply chains under returns policy in both decentralized and centralized settings. Implications for setting returns contracts for achieving channel coordination with risk considerations are discussed. Some other recent research works which analyse the risk issues in supply chain management include a qualitative discussion on proactive supply management and its close relationship with risk management (Smeltzer & Siferd 1998), a quantitative analysis of the role of intermediaries in supply chains to reduce financial risk (Agrawal & Seshadri 2000), a mean-variance analysis of single echelon inventory problems (Chen & Federgruen 2000), a study of the risk-free perishable item returns policy with a risk neutral retailer in a two-echelon supply chain (Webster & Weng 2000), an investigation of the use of capacity options in managing risk from demand uncertainty (Tan 2002), an analysis of the use of commitment-option for supply chain contract setting with forecast updates (Buzacott et al. 2003), a study on contracting scheme with risk preferences considerations (Bassok & Nagarajan 2004), a mean-variance analysis for the newsvendor problem with and without the opportunity cost of stock out (Choi et al. 2007a), and a study on channel coordination in supply chains under mean-variance objectives (Choi et al. 2007b)

3. Supply chain model

Consider a two-echelon supply chain with one manufacturer and one retailer. The retailer sells a fashionable product and faces an uncertain market demand. The manufacturer bears a unit product cost of c and sells the product to the retailer with a unit wholesale price w. For the retailer the unit product's selling price is r. At the end of the selling season, there is a salvage market in which any product leftover can be salvaged at a unit price v. Let the market demand faced by the retailer be x with a probability density function $f(x)$, and a corresponding cumulative distribution function $F(x)$. We assume that there is a one-to-one mapping between $F(\cdot)$ and its argument. We consider the following sequence of action: The manufacturer will first announce the wholesale price and other parameters (with respect to different kinds of contracts) to the retailer, the retailer will react by placing an order with a quantity q. We assume that the manufacturer can always fulfil the required order quantity placed by the retailer. For a notational purpose, define:

$$\xi(q) = 2q\int_0^q F(x)dx - 2\int_0^q xF(x)dx - \left(\int_0^q F(x)dx\right)^2$$

Table 1 below gives the profit, expected profit, standard deviation of profit of the simple supply chain described above. Observe that the manufacturer is risk free and can always make a positive profit when the wholesale price is larger than the production cost under this simple supply chain.

	Supply Chain	Retailer	Manufacturer
P	$(r-c)q-(r-v)(q-x)^+$	$(r-w)q-(r-v)(q-x)^+$	$(w-c)q$
EP	$(r-c)q-(r-v)\int_0^q F(x)dx$	$(r-w)q-(r-v)\int_0^q F(x)dx$	$(w-c)q$
SP	$(r-v)\sqrt{\xi(q)}$	$(r-v)\sqrt{\xi(q)}$	0

Table 1. Profit, Expected Profit, and Standard Deviation of Profit of the Simple Supply Chain without Additional Contracts

We now consider two kinds of contracts, the buy-back contract and the wholesale-pricing profit-sharing contract, in the following.

3.1 Buy-back contract

Under the buy-back contract, by the end of the selling season, the retailer can return the unsold products to the manufacturer for a partial refund with a unit buy-back price b, where $v \le b < w$. The returned products have a unit value of v to the manufacturer. We can derive the profit, expected profit, and standard deviation of profit under the buy-back contract for the supply chain, the retailer, and the manufacturer respectively as shown in Table 2 (see Choi et al. 2008 for the details of derivations).

	Supply Chain	Retailer	Manufacturer
P	$(r-c)q-(r-v)(q-x)^+$	$(r-w)q-(r-b)(q-x)^+$	$(w-c)q-(b-v)(q-x)^+$
EP	$(r-c)q-(r-v)\int_0^q F(x)dx$	$(r-w)q-(r-b)\int_0^q F(x)dx$	$(w-c)q-(b-v)\int_0^q F(x)dx$
SP	$(r-v)\sqrt{\xi(q)}$	$(r-b)\sqrt{\xi(q)}$	$(b-v)\sqrt{\xi(q)}$

Table 2. Profit, Expected Profit, and Standard Deviation of Profit under the Buy-back Contract

Notice that the supply chain's expected profit and standard deviation of profit are not affected by the presence of the buy-back contract.

3.2 Wholesale pricing and profit sharing contract

Under the wholesale pricing and profit sharing contract, the manufacturer controls the wholesale price w, where w can be set to be c, i.e., the manufacturer is supplying at cost and makes zero profit from the direct supply. On the other hand, the manufacturer will share the retailer's profit with a proportion of $(1-\alpha)$, where $0<\alpha<1$. To be specific, we can derive the following the profit, expected profit and standard deviation of profit under the wholesale pricing and profit sharing contract for the supply chain, the retailer, and the manufacturer, respectively:

	Supply Chain	Retailer	Manufacturer
P	$(r-c)q-(r-v)(q-x)^+$	$\alpha[(r-w)q-(r-v)(q-x)^+]$	$(w-c)q+(1-\alpha)\cdot$ $[(r-w)q-(r-v)(q-x)^+]$
EP	$(r-c)q-(r-v)\int_0^q F(x)dx$	$\alpha[(r-w)q-(r-v)\int_0^q F(x)dx]$	$(w-c)q+(1-\alpha)\cdot$ $[(r-w)q-(r-v)\int_0^q F(x)dx]$
SP	$(r-v)\sqrt{\xi(q)}$	$\alpha(r-v)\sqrt{\xi(q)}$	$(1-\alpha)(r-v)\sqrt{\xi(q)}$

Table 3: Profit, Expected Profit, and Standard Deviation of Profit under the Wholesale Pricing and Profit Sharing Contract

Remarks and findings:

i. Please notice that under both buy-back contract and the wholesale pricing and profit sharing contract, the expected profit functions of both the retailer and supply chain are concave in q, and their standard deviation of profit functions are increasing in q (see Choi et al. 2007a for more details).

ii. A direct observation from the expected profit and standard deviation of profit expressions for the manufacturer in Tables 1, 2 and 3 indicates that the manufacturer is basically risk free under the simple supply chain without additional contracts. However, under both the buy-back contract and wholesale pricing and profit sharing contract, the manufacturer needs to bear a higher risk. As a result, depending on the degree of risk aversion of the manufacturer, exercising one of these contracts is not always beneficial because the risk level for the manufacturer is higher.

iii. From Tables 1, 2 and 3, we can see that the sum of retailer's SP and manufacturer's SP equals the supply chain's SP. The same applies for the expected profit EP. As a result, a change of the contract parameter, of either the buy-back contract and the wholesale pricing and profit sharing contract, can lead to a reallocation of benefit (expected profit) and risk (standard deviation of profit) between the manufacturer and the retailer. Bargaining power hence plays a crucial role especially for the wholesale pricing and profit sharing contract.

4. Mean-variance decision models

We now consider the above proposed supply chain in which the manufacturer acts as a supply chain coordinator. Here, instead of maximizing the supply chain's expected profit, the manufacturer adopts the following MV objective for the supply chain:

$$(P1) \qquad \max_q EP_{SC}(q) \quad s.t. \; SP_{SC}(q) \le k_{SC}.$$

The objective of (P1) is to maximize the supply chain's expected profit subject to a constraint on the supply chain's standard deviation of profit, where k_{SC} is a positive constant. Represent by $q_{SC,EP*} = F^{-1}[(r-c)/(r-v)]$ the product quantity which maximizes $EP_{SC}(q)$. The efficient frontier for (P1) can be constructed with $q \in [0, q_{SC,EP*}]$, and $[0, q_{SC,EP*}]$ is the efficient region. In (P1), a smaller k_{SC} implies that the manufacturer (who is the decision maker) is more conservative and risk averse. We thus call k_{SC} the *supply chain's risk aversion threshold*. Notice that when $k_{SC} \in [0, SP_{SC}(q_{SC,EP*})]$, a smaller value of k_{SC} would lead to a smaller optimal quantity for (P1) because in this region: $EP_{SC}(q)$ is increasing and concave, $SP_{SC}(q)$ is increasing, and the constraint $SP_{SC}(q) \le k_{SC}$ is active. When $k_{SC} > SP_{SC}(q_{SC,EP*})$, the SP constraint becomes "inactive" as the optimal solution is always $q_{SC,EP*}$. Represent the optimal solution of (P1) by $q*$. It is easy to show that $q*$ exists and can be uniquely determined (see Choi et al. 2007a for the details). Similar to the model setting in (P1), the retailer's decision making problem is modelled as follows,

$$(P2) \qquad \max_q EP_R(q) \quad s.t. \; SP_R(q) \le k_R.$$

In (P2), the retailer tries to maximize his expected profit with the corresponding standard deviation of profit under control, i.e., $SP_R(q) \le k_R$, where k_R is a positive constant and it is the *retailer's risk aversion threshold*. When the manufacturer has specified the details on the wholesale price and other contract parameters, the retailer will determine an order quantity q_{R*} which optimizes (P2). Observe that there exists a unique $q_{R,MV*}$ (see Choi et al. 2007a for the details).

In general, $q*$ and $q_{R,MV*}$ are different. In this chapter, we consider *the best product quantity for the supply chain in the mean-variance domain as* $q*$. As a consequence, the manufacturer who acts as the supply chain coordinator can consider using some incentive alignment schemes to try to entice the retailer to order in a quantity which is equal to $q*$. We will now explore how the buy-back contract and the wholesale pricing and profit sharing contract can help to achieve this kind of coordination in a mean-variance domain. We separate the analysis into two parts in the next two sections.

5. Coordination by the buy-back contract in the mean-variance domain

Under the presence of the buy-back contract, we rewrite ($P2$) into ($P2(b)$) as follows,

$$(P2(b)) \qquad \max_q EP_R[q;b]$$
$$s.t. \;\; SP_R[q;b] \le k_R,$$

where $EP_R[q;b] = (r-w)q - (r-b)\int_0^q F(x)dx$, $SP_R[q;b] = (r-b)\sqrt{\xi(q)}$ (see Table 2), and b is the buy-back price offered by the manufacturer. Denote the optimal order quantity for ($P2(b)$) by $q_{R,BB*}(b)$. Following the approach in Choi et al. (2008), for any given b, we define the following:

$$q_{R,2*}(b) = \arg_q\{SP_R(q \mid b) - k_R = 0\}, \tag{1}$$

$$q_{R,1*}(b) = F^{-1}[(r-w)/(r-b)]. \tag{2}$$

Notice that $q_{R,1*}(b)$ is the order quantity which maximizes the retailer's expected profit with a given b. The following procedure, Procedure 1, provides the steps to identify the buy-back price which can achieve coordination ($b_{SC,MV*}$):

Procedure 1

Step 1. Compute $q*$ by solving ($P1$).

Step 2. Determine a parameter b_{1*} which makes $q_{R,1*}(b) = q*$ as follows:

$$q_{R,1*}(b) = q*$$
$$\Leftrightarrow F^{-1}[(r-w)/(r-b)] = q*$$
$$\Leftrightarrow b = r - [(r-w)/F(q*)]$$
$$\therefore b_{1*} = r - [(r-w)/F(q*)]. \tag{3}$$

Step 3. Determine a parameter b_{2*} as follows:

$$q_{R,2*}(b) = q*$$
$$\Leftrightarrow SP_R(q* \mid b) - k_R = 0$$
$$\Leftrightarrow (r-b)^2\xi(q*) = k_R^2$$
$$\Leftrightarrow b = r - k_R / \sqrt{\xi(q*)} \text{ or } b = r + k_R / \sqrt{\xi(q*)}.$$

Since $b < r$, $b = r + k_R / \sqrt{\xi(q^*)}$ is rejected:

$$\therefore b_{2^*} = r - (k_R / \sqrt{\xi(q^*)}) . \quad (4)$$

Step 4. Check for the feasibility of $b_{SC,MV^*} = b_{1^*}$:

- If $SP_R(q_{R,1^*} \mid b_{1^*}) \le k_R$, then $q_{R,BB^*}(b_{1^*}) = q_{R,1^*}(b_{1^*})$. Thus, setting $b = b_{1^*}$ would yield $q_{R,BB^*}(b_{1^*}) = q_{R,1^*}(b) = q^*$. Set $b_{SC,MV^*} = b_{1^*}$ and stop.
- If $SP_R(q_{R,1^*} \mid b_{1^*}) > k_R$, then $q_{R,BB^*}(b_{1^*}) = q_{R,2^*}(b_{1^*})$. However, setting $b = b_{1^*}$ would not yield $q_{R,BB^*}(b_{1^*}) = q^*$ since setting $b = b_{1^*}$ can only achieve $q_{R,1^*}(b) = q^*$, but here $q_{R,BB^*}(b_{1^*}) = q_{R,2^*}(b)$. Go to Step 5.

Step 5. Check for the feasibility of $b_{SC,MV^*} = b_{2^*}$ (after Step 4):

- If $SP_R(q_{R,1^*} \mid b_{2^*}) > k_R$, then $q_{R,BB^*}(b_{2^*}) = q_{R,2^*}(b_{2^*})$. Thus, setting $b = b_{2^*}$ would yield $q_{R,BB^*}(b) = q_{R,2^*}(b) = q_{SC,MV^*}$. Set $b_{SC,MV^*} = b_{2^*}$ and stop.
- If $SP_R(q_{R,1^*} \mid b_{2^*}) \le k_R$, then $q_{R,BB^*}(b_{2^*}) = q_{R,1^*}(b_{2^*})$. In this case, setting $b = b_{2^*}$ can only achieve $q_{R,2^*}(b) = q^*$ (but not $q_{R,1^*}(b_{2^*}) = q^*$ which implies $q_{R,BB^*}(b_{2^*}) = q^*$). Thus, we are not able to achieve $q_{R,BB^*}(b_{2^*}) = q^*$. In this situation, setting both $b_{SC,MV^*} = b_{1^*}$ and $b_{SC,MV^*} = b_{2^*}$ cannot achieve coordination in the MV domain.

Procedure 1 gives us the detailed steps for identifying the buy-back price which can achieve coordination in a mean-variance domain. Since the buy-back price is bounded between v and w, i.e. $v \le b < w$, a checking on the computed value of b_{SC,MV^*} with respect to this bound is a required feasibility test.

6. Coordination by the wholesale pricing and profit sharing contract in the mean-variance domain

With the wholesale pricing and profit sharing contract, we rewrite ($P2$) into $(P2(w,\alpha))$ as follows,

$$(P2(w,\alpha)) \qquad \max_q EP_R[q; w, \alpha]$$
$$s.t.\ SP_R[q; w, \alpha] \le k_R,$$

where $EP_R[q;w,\alpha] = \alpha[(r-w)q - (r-v)\int_0^q F(x)dx]$, $SP_R[q;w,\alpha] = \alpha(r-v)\sqrt{\xi(q)}$ (see Table 3), α is the proportion of profit that the retailer takes and w is wholesale price offered by the manufacturer to the retailer. Represent the optimal quantity which maximizes $(P2(w,\alpha))$ by $q_{R,WP^*}(w,\alpha)$. Similar to the idea in Section 4, we define the following:

$$q_{R,2^*}(w,\alpha) = \arg_q\{SP_R(q \mid w,\alpha) - k_R = 0\} , \quad (5)$$

$$q_{R,1^*}(w) = F^{-1}[(r-w)/(r-v)] . \quad (6)$$

Notice that $q_{R,1^*}(w)$ is the order quantity which maximizes the retailer's expected profit with a given w and it is independent of α. Suppose that α is initially set to be α_o (where $0 < \alpha_o < 1$) upon the negotiation between the retailer and the manufacturer. The following procedure gives the steps to identify the wholesale price and/or the necessary adjustment in α in order to achieve coordination in the mean-variance domain:

Procedure 2

Step 1. Compute q^* by solving ($P1$).

Step 2. Determine a parameter w^* which makes $q_{R,1^*}(w) = q^*$ as follows:

$$q_{R,1^*}(w) = q^*$$

$$\Leftrightarrow F^{-1}[(r-w)/(r-v)] = q^*$$

$$\therefore w^* = r-(r-v)F(q^*). \tag{7}$$

Step 3. Determine a parameter α^* which makes $q_{R,2^*}(w,\alpha) = q^*$ as follows:

$$q_{R,2^*}(w,\alpha) = q^*$$

$$\Leftrightarrow SP_R(q^* \mid w,\alpha) - k_R = 0$$

$$\Leftrightarrow \alpha(r-v)\sqrt{\xi(q^*)} = k_R$$

$$\therefore \alpha^* = \frac{k_R}{(r-v)\sqrt{\xi(q^*)}}. \tag{8}$$

Step 4. Check for the feasibility of setting the wholesale price $w = w^*$ with $\alpha = \alpha_o$.

- If $SP_R(q_{R,1^*}(w=w^*) \mid \alpha_o) \le k_R$, then setting $w = w^*$ with $\alpha = \alpha_o$ can already make $q_{R,WP^*}(w,\alpha) = q^*$. Thus, we can set the wholesale price $w = w^*$ with $\alpha = \alpha_o$, and stop; otherwise, go to Step 5.

Step 5. Check for the feasibility of setting another value of α.

- If $SP_R(q_{R,1^*}(w=w^*) \mid \alpha_o) > k_R$, then:
  - Option 1: The manufacturer can try to negotiate with the retailer and set a value of $\alpha = \alpha_1$ (where $0 < \alpha_1 < 1$) with which $SP_R(q_{R,1^*}(w=w^*) \mid \alpha_1) \le k_R$.
  - Option 2: The manufacturer can check and see if $\alpha^* < 1$. If $\alpha^* < 1$, then the manufacturer can propose to the retailer by setting a value of $\alpha = \alpha^*$ (where $0 < \alpha^* < 1$) which can make $q_{R,WP^*}(w,\alpha) = q^*$.

Procedure 2 provides to us some guidelines for determining the contract parameters of the wholesale pricing and profit sharing contract which can help to achieve coordination in the mean-variance domain.

7. Conclusion

In this chapter, we have conducted a mean-variance analysis for supply chains under a buy-back contract and a wholesale pricing and profit sharing contract. We characterize in the supply chain the return and the risk by the expected profit and the standard deviation of profit, respectively. We focus our discussions on the centralized supply chains. From the structural properties of the supply chain, we find that the buy-back price and the wholesale price are simply internal money transfers between the retailer and the manufacturer. A change of these prices will lead to a change of the profit and risk sharing between the retailer and the manufacturer. We illustrate how a buy-back contract and a wholesale pricing and profit sharing contract can coordinate a supply chain in a mean-variance domain. Efficient procedures are proposed. The necessary and sufficient conditions for the optimal contract parameters to be found in its feasible region can then be determined. Observe that channel coordination in the mean-variance domain is not always achievable. This finding is important because when we ignore the risk aversions of the individual supply chain members (as what most papers in the literature assume), channel coordination can always be achieved by setting a buy-back contract and a wholesale pricing and profit sharing contract. However, in the real-world, different supply chain members have different degrees of risk aversion, and hence a realistic contract should be set with respect to the risk aversions of these individual decision makers. Moreover, intuitively, when the risk aversions between the supply chain coordinator and the retailer are too far away, channel coordination may not be achievable and this point can be revealed by using our analytical models. From the studies in this chapter, we can see that the mean-variance model can provide a systematic framework for studying channel coordination issues in stochastic supply chain models with risk and profit considerations. This framework can be further extended and used to study a large variety of supply chain contracts.

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7

Developing Supply Chain Management System Evaluation Attributes Based on the Supply Chain Strategy

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Taiwan

1. Introduction

Given constantly fluctuating market demands, short life cycles of products and global market trends, companies must effectively design, produce and deliver products and services (Christopher & Juttner, 2000). A Supply Chain Management (SCM) system involves managing and coordinating all activities associated with goods and information flows from those raw materials sourcing to product delivery and, finally, to the end customers. A SCM system incorporates numerous modules of supply chain planning and execution, e.g., supply chain network configuration, demand planning, manufacturing planning and scheduling, distribution planning, transportation management, inventory and warehouse management, and supply chain event management, etc. This is why more companies are seeing SCM systems as the key to enhance the transparency, sharing, and trust of their supply chains.

Min & Zhou (2002) postulated that information technology (IT) provides the impetus for supply chain cooperation and re-engineering. Here, a SCM system is defined as an integrated enterprise information system (EIS) to realize the integration and collaboration of different stages within a supply chain and owns analytical capabilities to produce planning solutions, strategic level decisions and executing tasks of supply chain. A lot of companies invest large money and efforts in SCM applications to increase their competitive advantages and improve overall supply chain efficiency. As a SCM system becomes more organizationally encompassing, so that its selection is complicated in nature rather than just traditional information system (IS) selection (Sarkis & Sundarraj, 2000). However, many companies install their SCM systems hurriedly without fully understanding the implications for their business or the need for compatibility with overall organizational goals and strategies. The result of this hasty approach is failed projects or weak systems whose logics conflict with organizational goals. However, the impact of bad decision can be high not only in system operations but in terms of its impact on management attitude.

Davenport (1998) emphasized the technical factors are not the main reason EIS fail, however, the biggest problems are business problems. The performance of a SCM system basically relates to the degree of match between the available system functionalities and the company's requirements and also between the logic assumed in the system and that of the supply chain. Companies need to reconcile the technological imperatives of SCM systems with the business needs. Additionally, the supply chain implications, high resource commitment, high potential business benefits and risks associated with SCM systems make the selection and adoption a much more complex exercise in business strategies and innovation than any other software package. It seems obvious that we can not solve the SCM selection problem simply by grinding through a mathematical model or computer algorithm. A SCM assessment approach needs to be developed to include both strategic and technical considerations.

This chapter presents a decision analysis process to select an appropriate SCM system considering the strategies and operation routines of supply chain to link with the supply chain objectives of a company. However, this process emphasizes on a systematic SCM objective discussion and evaluating attribute development process, not on the mathematical decision-making models. Then, the process provides a structured methodology to link the objective structure with the decision-making model for choosing the proper attributes and evaluation guideline. An empirical case in Taiwan is described to demonstrate the practical viability of the proposed method.

2. Information system selection problem

Several methods have been proposed for selecting an adequate SCM or IS. In practice, scoring (Lucas, H. C. & Moore, 1976) and ranking methods (Buss, 1983) are very simple to implement the IS selection so that they are popular and applied widely. However, the primary limitation of scoring and ranking methods is too simple to truly reflect opinions of decision makers (Santhanam & Kyparisis, 1996). Mathematical optimization methods such as goal programming, 0-1 programming, and non-linear programming methods are also applied to resource optimization for selecting an IT system. Santhanam & Kyparisis (1995, 1996) presented a nonlinear programming model to optimize resource allocation. It considered the interdependencies of resources related to the assessment indicators. Lee & Kim (2001, 2000) adopted the analytic network process (ANP) to 0-1 goal programming model to choose an appropriate IT system. Talluri (2000) categorized SCM systems into three domains, i.e., strategic, tactical and operational planning systems, and then created a 0-1 goal programming model to optimally combine the three domains. However, the applicability of these above mathematical optimization methods is often weakened by sophisticated mathematic models or limited attribute set to carry out in a real world. In an EIS selection decision, like Enterprise Resource Planning (ERP) and SCM, some attributes are not readily intangible and not easy to understand by managers. A narrow focus on the tangible measures usually hinders a thorough and accurate picture of the true value of strategic objectives to organizations.

Fuzzy set theory is developed for solving problems in which descriptions of activities and observations are imprecise, vague, and uncertain. Fuzzy set theory has been used in IS selection, since the characteristics of a suitable IS selection are descriptive and ill-defined. For example, Lee (1996a) built a structure model of risk in software development and evaluated the rate of aggregative risk by fuzzy set theory. He aggregated the fuzzy grade of risk and the fuzzy grade of importance to evaluate the rate of aggregative risk in software development phase. Next, Lee (1996b) extended his model to propose two algorithms to tackle the rate of aggregative risk in a fuzzy group decision-making environment during any phase of the life cycle. Later, Chen (2001) defuzzied the both grades first to simplify the heavy and complicated calculations in Lee's model to evaluate the rate of aggregative risk in software development. However, these studies focused their attentions on the risks in software development phase and did not discuss other important factors on IS evaluation. Wei & Wang (2004) proposed a comprehensive ERP selection framework to select an ERP system using fuzzy multi-attribute decision-making (FMADM) approach. Their method combined the objective ratings and subjective evaluations to aggregate a synthetic index to assess ERP alternatives. Wei et al. (2007) applied the fuzzy integral method to develop a SCM selection framework. These fuzzy assessment approaches provide good mathematical decision-making methods to deal with ambiguity of human judgments.

Strategic discussions of effective supply chain management play a very important role in constructing the supply chain and business model. Many researchers emphasized that it is necessary to consider the strategic factors for selecting a SCM system. Fisher (1997) offered a framework to help managers to understand the nature of the demand for their products and devise the supply chain that can best satisfy that demand. Jiang & Klein (1999a, 1999b) proposed that the selection of IT projects varies by strategic orientation. They used a questionnaire to assess the strategic relevance of IT systems in an organization and measure the important IT system selection criteria. Their research results allow managers to position selection criteria according to their strategic use of IT.

Generally, a SCM system selection is a group multiple-attribute decision-making (MADM) problem, in which, some measures are not easily quantifiable. But the technical challenges, however great, are not the main reasons which lead to a SCM project fail. The biggest problems are business problems (Ash & Burn, 2003). In the next section, a systematic procedure is proposed to construct the objective structure taking into account company strategies and thus extract the associated attributes for evaluating SCM systems. The method also can help decision makers to set up a consistent evaluation guideline and facilitates the group decision-making process.

3. The SCM system selection objective and attribute development method

This section provides a process to develop appropriate objectives, attributes and detailed evaluation contents for evaluating SCM systems. To clearly present the proposed SCM implementation objective and attribute development method, a stepwise procedure is first described.

Step 1. Create a SCM system implementation project team and identify the characteristics of the supply chain.

Step 2. Develop the strategic objectives of the supply chain.

Step 3. Construct the supply chain structure.

Step 4. Establish the fundamental and means objective structures of the SCM implementation project.

Step 5. Extract the suitable attributes to structure the attribute hierarchy and develop the detailed attribute identifications.

Step 6. Screen the unqualified SCM systems.

Step 7. Evaluate the SCM systems.

Figure 1 displays the comprehensive procedure of the proposed method.

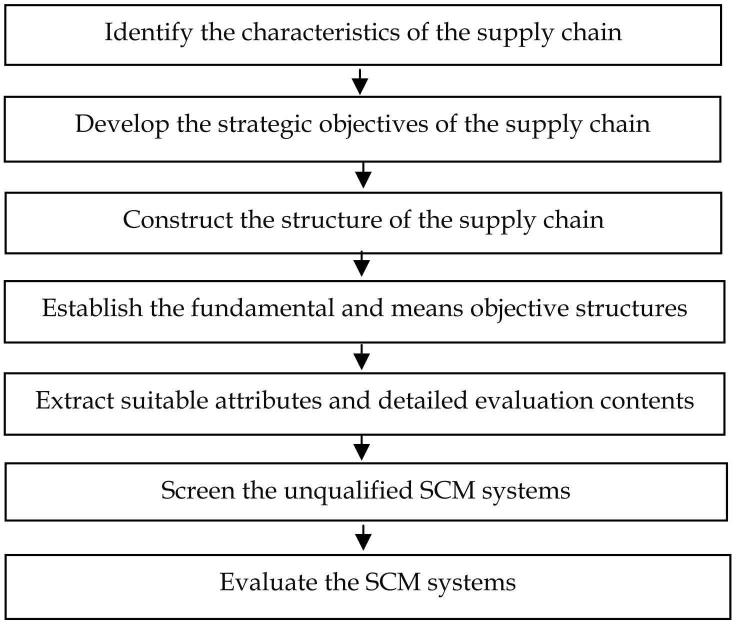

Figure 1. the SCM system evaluation attribute development and SCM system selection framework

3.1 Identify the characteristics of the supply chain

Elucidating the structure of a supply chain is necessary to model the supply chain links. To fully exploit the utmost benefits of these links, the project team should clarify the unique characteristics of each interconnected link (Min & Zhou, 2002). Correspondingly, the project team must identify the industry characteristics, client needs, product life cycles, as well as other crucial concerns to widely collect obstacles, information, and environmental trends of the current supply chain in order to develop the goals and network structure of the supply chain. Meanwhile, the company must perceive its current positions and influence in the supply chain. Such perceptions will help the project team in clarifying the scope of business process integration in the supply chain link model that the company can support and handle.

SCM system vendors and systems will significantly influence the long-term supply chain performance in the future (Talluri, 2000). As anticipated, the relationship with SCM system vendors should be also a long-term and close partnership. Thus, comprehensively accumulating information of related SCM system vendors and systems in the initial selection stage is essential, as well as ensuring that the survey includes less widely known vendors to avoid a situation in which more feasible projects are overlooked.

3.2 Develop the strategic objectives of the supply chain

Performance expectations of strategic objectives in the supply chain should correspond to the competitive strategies of the company. Three steps can be adopted in analyzing the elements of the supply chain and identifying the objectives to achieve strategy conformity

(Chopra & Meindl, 2001): (1) understanding the customers, i.e., the quantity of the product needed in each lot, the response time that customers are willing to tolerate, the diversity of the product line, the service level required, product price and the desired rate of innovation in the product (Fisher, 1997), (2) understanding the supply chain, i.e., effectively respond to broad consumer demands, meet short lead times, handle diverse products, create highly innovative products and strive for a high service level, and (3) achieving strategic fit, i.e., accommodate customer requirements and supply chain capabilities and ensure that all functions in the supply chain have consistent strategies that support the competitive ones. Other factors must be deliberated in developing the supply chain model, including the cooperativeness of major suppliers and customers, competitiveness of the industry and bargaining power of the company.

The strategic objectives of the supply chain offer a solid basis for decision-making and a stable reference point for ill-structured decision situations. The strategic objectives guide the ultimate goals that the project team should strive to achieve; thus they also serve as the mechanism to harmonize the opinions of different individuals within the project team.

3.3 Construct the supply chain structure

The significant emphasis on coordination and integration is strongly linked to the development of more effective and longer-term relationships between supply chain members. To fully exploit the benefits of the supply chain network, the project team should clarify the unique characteristics of each interconnected link. Making the scope of the SCM system implementation project clearly and recognizing applicable supply chain network are very important. Although there is no systematic approach to organize a supply chain structure, we suggest to follow the methods proposed by Lambert & Cooper (2000). Figure 2 indicates the supply chain network construction method.

1) Members of the supply chain. Integrating and managing all business processes into a SCM system would be inappropriate and expensive. When constructing the supply chain network, identifying who the members of the supply chain are is a prerequisite. Allocating scarce resources to the key links involves determining which parts of the supply chain must be highly prioritized as major links that depend on the core competence and contributions of this supply chain member. Recognize operational roles and decision rights for different members to align the strategic objectives of the supply chain with them.
2) Structural dimensions of the supply chain network. To compromise the dilemma between the complexity of supply chain model and the practicing applicability of the SCM system, the managers should choose the suitable scope of partnerships for particular links. Two dimensions, horizontal and vertical structures, exist in the supply chain network. The horizontal dimension provides the number of tiers across the supply chain. Correspondingly, the vertical structure refers to the number of suppliers and customers represented within each tier. The managers need to scrutinize which aspects of the supply chain should be modeled and identify the crucial boundaries of the supply chain model. The degree of strategic and operational coordination determines the relationship between a specific sypply chain member and our company.
3) Characteristics of supply chain links. Traditionally, many companies regard their own firms as the focal companies in the supply chain (Verwijmeren, 2004). Actually, sometimes a company is a primary member for a specific organization, sometimes it is a

supportive role in the supply chain, and it more often performs both primary and supportive operations. The managers must understand their interrelated roles in the supply chain according to a networked organization perspective. According to supply chain strategic objectives and linkage patterns, the project team can confirm the requirements of major processes in the supply chain model, which will be converted into the specifications of SCM system fundamentals when developing and evaluating an adequate SCM system. After the major processes are selected, the screening will extend to generate internal and external supply chain requirements with the matrix of management priorities and resource allocation.

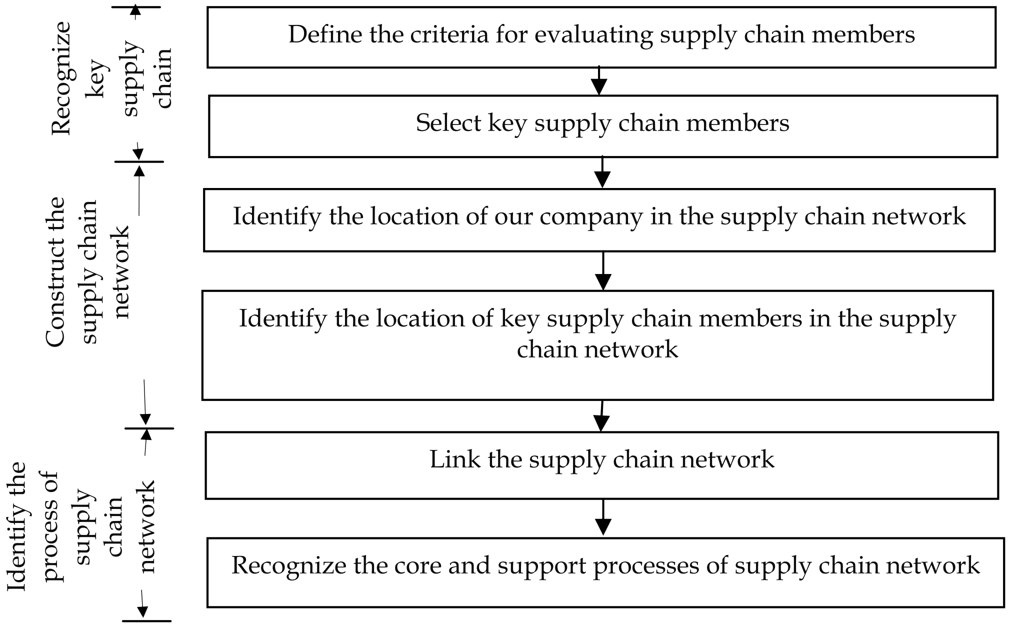

Figure 2 supply chain network construction process

According to supply chain strategic objectives and linkage patterns, the project team can confirm the requirements of major processes in the supply chain model, which will be converted into the specifications of SCM system fundamentals when developing and evaluating an adequate SCM system.

3.4 Establish the fundamental and means objective structures of the SCM implementation project

Structuring the objectives means organizing them so that the project team can describe in detail what the company wants to achieve and the objectives should be incorporated in an appropriate way into the decision model. Many different, even conflicting, objectives might be considered for developing a multiple objectives decision model to select a suitable SCM system. All objectives derived from the strategic objectives will be structured systematically. The objectives can be classified into fundamental objectives and means objectives (Clemen, 1996). The fundamental objectives are those that are important simply because they reflect what the decision makers really want to accomplish. The means objectives describe how they can help to achieve other important objectives.

The fundamental objectives are organized into a hierarchy and they indicate the direction in which the project team should strive to do better. The upper levels in the hierarchy refer to more general objectives and the lower levels comprise some important postulations of the upper objectives. Two methods can be used to establish the fundamental SCM objectives hierarchy, namely, top-down decomposition and bottom-up synthesis. By the procedure of top-down decomposition, the project team can ask, "What do you mean by that?". The answers reveal these lower-level fundamental objectives explain what is meant by the upper-level objective. On the other hand, team members can start from a lower fundamental objective upward by asking, "Of what more general objective is this aspect?" to find a more general objective by means of the bottom-up synthesis procedure. The upper levels in the fundamental objective hierarchy refer to more general objectives and the lower levels contain important elaborations of the upper objectives. As organizing the fundamental objectives hierarchy, the project team must keep in mind to pay attention to the limitation of decision elements and the alternation of business environment at any time.

Means objectives are organized into networks. Having formulated these means objectives, the project team can assure the ways to accomplish the preceding fundamental objectives. In addition, they can narrow the set of SCM candidates and develop the detailed specifications of attributes to evaluate the SCM systems. The project team can create a means objective apart from fundamental objectives by asking, "How could you achieve this?". The answers identify the corresponding means objectives and describe the linking relations among them. Then, asking the question, "Why is that important?", can help to distinguish the fundamental and means objectives and composite the means objectives toward fundamental objectives. Table 1 summaries the fundamental objective hierarchy and means objective network construction method.

	Fundamental objectives	Means objectives
To move: *Ask:*	Downward in the hierarchy *"What do you mean by that?"*	Away from Fundamental objectives *"How could you achieve this?"*
To move: *Ask:*	Upward in the hierarchy *"Of what more general objective is this aspect?"*	Toward Fundamental objectives *"Why is that important?"*

Table 1. Objective structure construction method (Clemen, 1996)

3.5 Extract the suitable attributes to structure the attribute hierarchy

After creating the structure of objectives, the project team can derive the attributes pertinent to evaluating each SCM system. Both quantitative and qualitative attributes that satisfy the strategies and goals of the company should be involved. Proper attributes guide to fulfill key requirements of a company such as strategic concerns and operational needs for assessing a SCM system and mapping out the project characteristics. After the factors addressed in previous studies are organized, we suggest to categorize SCM system selection attributes into four domains, including strategy, project, software system, and vendor factors. Some suggested attributes are introduced below.

1) Strategy factors: attributes that concern with the strategic objectives of the supply chain, for example, customer demand support, supply chain capability, domain knowledge support, and supply chain model design
   i. Customer demand support. A SCM system should support the needs for each targeted segment, like product position in the market, customer segments, product cycle, and service level, etc.
   ii. Supply chain capability. There are many types of supply chains, each of which is designed to perform different tasks well. According to Fisher (1997), it includes the responsibility of the supply chain and the efficiency of the supply chain. A SCM system must satisfy the charecteristics of the supply chain.
   iii. Domain knowledge support. Traditional SCM packages are generic in design, but they also need to meet a company wants to work specially. However, different industries may have different processes, operations, and other considerations. These systems are expected to provide the functional and domain knowledge fitness with the company's business processes. That is, the software should be designed to support the industry of the company.
   iv. Supply chain model design. The SCM system should be able to support the design of the supply chain model, including the plant and warehouse location, supply chain member choice, and supply chain membership formulation, etc
2) Project factors: attributes involved in managing the SCM system implementation project, such as total costs, implementation time, expected benefits, and project risks.
   i. Total costs. Usually, direct costs are easily measurable, while indirect costs require considerable effort to appraise. However, it is crucial to have comparative data across alternatives for evaluation purpose. These costs includes cost per module, total package cost, customization cost, annual maintenance cost, planning and implementation cost, consulting cost, installation and training cost, cost of upgrades and special hardware cost, etc.
   ii. Implementation time. Most of SCM systems failure originates in long implementation time and cost overspending. The project team should negotiate with the system vendors to estimate the implementation time of the SCM adoption project. A deliberate and detailed schedule is necessary to be planned and followed up.
   iii. Benefits. Like total costs, estimating the benefits exactly is difficult before the SCM adoption. Nonetheless, it is necessary to obtain comparative values on the benefits for evaluation purpose, as in the case of total costs. Many benefits can not calculated using monetary values, like enhancing operation efficiency, integrating and sharing information with supply chain members, improving the quality of decision-making, increasing the speed of response to customers. They are the main factors which attract companies to adopt a SCM system. Decision makers need to evaluate these benefits.
   iv. Risks. The project risk emanates basically from the budget of investment, the complexity of the system and the skill of project management. Many of these risks

stem from the intrinsic package design and the vendor's technology and experience, so should be carefully assessed during the evaluation process.

3) Software system factors: features of the SCM software system, including the system functionality, system flexibility, system integration, system reliability, user friendliness, and security.
   i. Functionality. Generally, this factor is the most significant attribute for most of companies. Different SCM software systems offer different functionalities and modules to meet the requirements of a company. Project team needs to examine whether the functionalities of a SCM system satisfies the requirements and operations. However, a lot of customization will lead to much cost and implementation time. Reducing the degree of customization is the main purpose to assess this attribute. In the Web era a SCM system needs to support Internet, network and e-commerce setups. High technology support for business integration is essential in broadening the marketing network.
   ii. Flexibility. The size of a company and its business process are hardly static and fluctuate with time. Flexibility offers the capability of a SCM system to support the needs of the business over its lifetime. The absence of flexibility will render the system corrupt and even obsolete. Firstly, the SCM system must be platform independent. All operating systems, communication systems and database servers should be implemented freely. Secondly, ease of customization and ease of development in house are critical factors whether the system can support the needs of the business in the future.
   iii. System integration. As mentioned above, a SCM system should be easily integrated with databases, data warehouses, operating systems and communication systems. Additionally, a SCM system must be easily integrated with other expanding SCM modules and EIS, like ERP, Manufacturing Execution System (MES) and Product Data Management (PDM), etc. System integration allows for the creation of one set of code that can be applied across a heterogeneous network without requiring users to have knowledge of where the components are physically resident.
   iv. Reliability. Moreover, faults occurred in the system run not only decrease productivity, but also diminish the confidence of users. Then the reliability of the system cannot be overemphasized during the evaluation process. The commonly used reliability measures are: number of faults in a fixed time interval and time between two faults. Additionally, the system recovery ability can complement the reliability issue.
   v. User friendliness. Employees cannot afford to spend a lot of time to learn a new software. User interface of the system has to be intuitive and reflect the mental picture of the business activities with which users are familiar. Easy to learning and easy to operating are very important factors which affect the success of a SCM system.
   vi. Security. The security of the databases and SCM system must be inviolable and information must be guarded from competitors and hackers. Security of the databases and of the SCM processes must be inviolable.
4) Vendor factors: attributes that pertain to vendors, like vendor's ability, implementation and maintenance ability, consulting service, and vendor's reputation.

i. Vendor's ability. In view of the expected longevity of a SCM system, the commitment of the SCM vendor to the product and his capability to support the system constitute crucial parameters. The system vendor should be able to support the global implementation missions and service jobs in the future. A SCM system requires technical maintenance support from the vendor. The pre-sales support, automated Web-based support and documentation support are accounted. Moreover, the vendor's R&D technology and the trainings that the vendor offers for users should also be evaluated.
ii. Implementation & maintenance ability. A SCM system requires sophisticated hardware and software system adoption during the implementation process. It may not only fit with the requirements of the company, but also support its complicated supply chain process. A good implementation methodology and experience of the vendor are crucial to adopt the SCM system successfully. More importantly, the maintenance and upgrade services would influence the life and performance of a SCM system after the implementation.
iii. Consulting services. Due to lack of understanding these SCM systems and their implications, management's difficulty in evaluating SCM alternatives and examining related projects imperatives is increasing at this early stage. For implementing the SCM system successfully, consulting service is a critical factor. The consultants facilitate the process of modules adoption, stabilize the applications and provide valuable experiences with the best practice. The experience of consultants, the cooperation degree between consultants and internal employees and the input resources density of the consultants constitute the quality and performance of consulting services.
iv. Vendor's reputation. Unless the vendor has a sustainable earning stream, the capability could be assessed like the market share, earning profile and the general health of the vendor's balance sheet. The vendors are asked to provide information which would enable the project team to assess them against basic commercial selection criteria, e.g. number of years in business, turnover, number of employees, research and development expenditure, product lines, industrial knowledge and experience, etc. Past performance and experience of the vendor as well as product are also considerable issues.

The project team can make reference to these attributes of prior studies. However, the fundamental objective hierarchy points out the important things that managers want to attain according to the strategic objectives of their supply chain. They had better developed their own critical objectives structure and select the appropriate attributes, which are measurable and be extracted from the fundamental objectives hierarchy, based on the current business environment and the requirements of the company. According Keeney (Keeney & Raiffa, 1993), the project team can examine and modify the attributes continually by some principles, e.g. the attributes should be complete, decomposable, non-redundant, operational and measurable, and minimal. Thus, the managers can perceive that these attributes are consistent with the company's objectives and strategies.

3.6 Screen the unqualified SCM systems

A large number of alternatives would be collected initially; hence we need a filtering mechanism to shorten the list of SCM candidates. The characteristics of the SCM implementation project, which the company wants, can be developed over a course of many meetings. The characteristics that reflect the requirements are transferred to a questionnaire or a checklist of the system specifications. Examining the means objectives network can help to scrutinize the system specifications and ensure these requirements can support the company's fundamental objectives. The listed vendors are requested to provide information in response to these specific questions. The project team can assess the information to eliminate the clearly unqualified vendors.

3.7 Evaluate the SCM systems

Many decision-making methods can be adopted to evaluate the various SCM or IS alternatives, like Delphi method, score method, ranking method, Analytic Hierarchy Process (AHP), fuzzy set theory, 0-1 programming method, etc. Despite the project team adopts any decision-making method to evaluate the SCM alternatives, the proper objectives and attributes development is the most critical process. Even if the project team does not employ any quantitative assessment method, a deeply and scrupulous examination or discussion can select an adequate SCM system. The development process of fundamental and means objective structure and decision-making model are summaried in Figure 3.

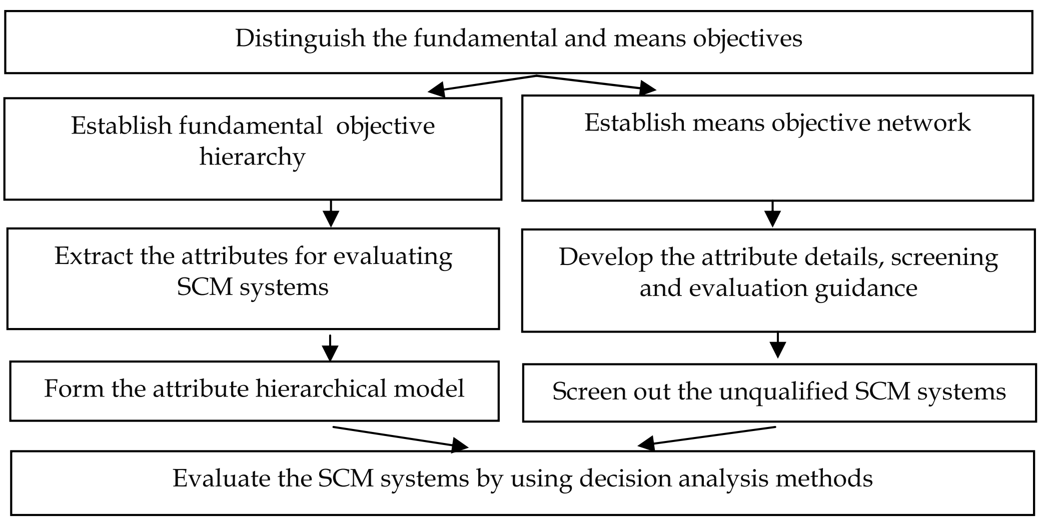

Figure 3. The objective structure and decision-making model development process

4. An actual evaluation

The proposed framework was applied to select an appropriate SCM system at a steel mill in Taiwan. This integrated steel mill produces plates, bars, wire rods, semi-finished products, and other steel products. After implementing the ERP system, the top management desired to enhance the effectiveness of its global supply chain by adopting a SCM system. The process of selecting the adequate SCM is described below.

Step 1. A project team involved seven senior managers was formed with the responsibility to formulate the project plan, integrate project resources, and select a suitable SCM system. Representatives of different user departments, information experts and consultants were also chosen to participate in the project team. The project team discussed the goals of the SCM system implementation project, the project scope, organizational strengths and weaknesses, potential alternatives, and other major concerns at the regular project team meeting. The team gathered information such as problems of the existing supply chain, industry characteristics, and client demands to recognize the characteristics of the supply chain. In addition, the project team held several promotional workshops to encourage employee engagement and support. These meetings produced numerous valuable recommendations, to which the project team responded during the project implementation to reduce resistance to the project.

Step 2. Because the steel industry is based on make-to-stock manufacturing principle, stock and cost are the most critical considerations. Following discussion among team members, the strategic objectives of their supply chain were defined as follows:

1) Supply the market demands at the lowest price under meeting quality requirements;
2) Minimize inventory in the entire supply chain to reduce the total holding cost;
3) Maximize productivity and turnover rate of equipments to lower the operating cost;
4) Select the adequate suppliers based on cost and quality;
5) Adopt the low cost logistics technologies;
6) Develop new products under the minimizing cost constraint.

Step 3. Determining which parts of the supply chain deserve management attention must be weighed against the capabilities, contributions, and priorities of the supply chain members to the steel mill. Based on the importance and priority to the steel mill, suitable supply chain network members were selected for consideration. The major links were the tier-1 key direct suppliers and clients, warehousing vendors and distributors in the supply chain. Some crucial operations of the other tiers, including indirect suppliers, customers and organizations in the supply chain, formed the monitoring links.

Step 4. The project team constructed the fundamental objective hierarchy and the means objective network. Figure 4 indicates the fundamental objective hierarchy. The ultimate goal was to “select an appropriate SCM system”. This goal were divided into four lower-level objective factors, namely strategy, project, system and vendor factors. For example, the project team discussed “What does choosing the most appropriate SCM system mean?” in the system factor aspect. Their answers included that the system has satisfied functionality and technology, high system flexibility, and system integration ability. The members further discussed “What does the complete functionality and technology mean?” to drill down the objectives of system functionality and technology. The answers lay in module functionality, system user friendliness, system reliability and quality, and system security. Similarly, the top-down decomposition method found the other objectives in level 3 and level 4 and established the practical meanings of these objectives.

Simultaneously, the project team synthesized the lower-level objectives into more general objectives to verify the consistency of the fundamental objective hierarchy and thus refined the hierarchical structure previously derived from the top-down decomposition method. Indeed, this process was iterative and the structure was not unique.

On the other hand, Figure 5 and 6 show the means objective networks of the SCM adoption project in the software system factors and vendor factors. For example, the project team started from an objective, functionality, the bottom of a system fundamental objective by asking the question, “How can the suitable module functionality be acheived?”. They

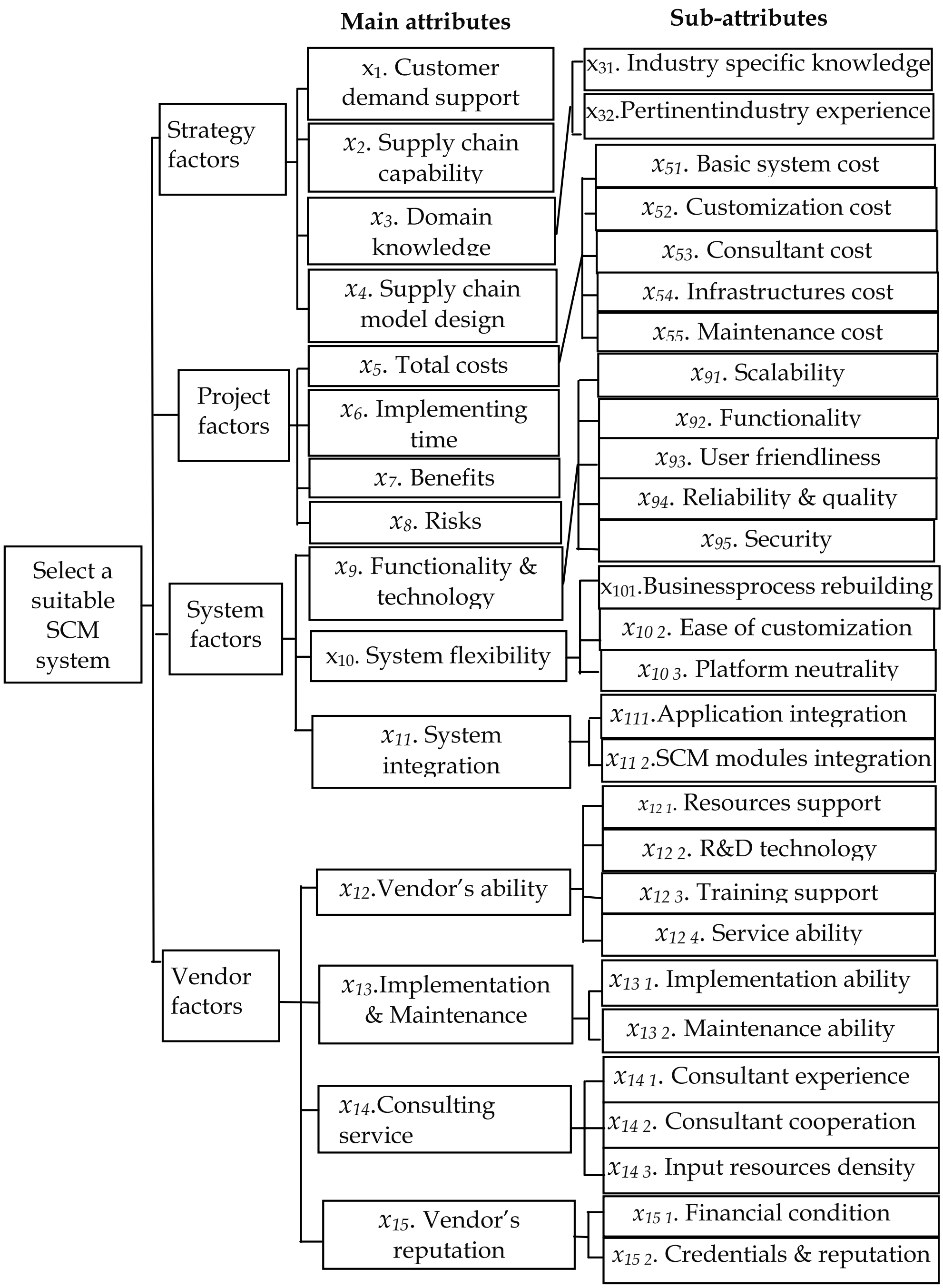

Figure 4. The fundamental objective hierarchy

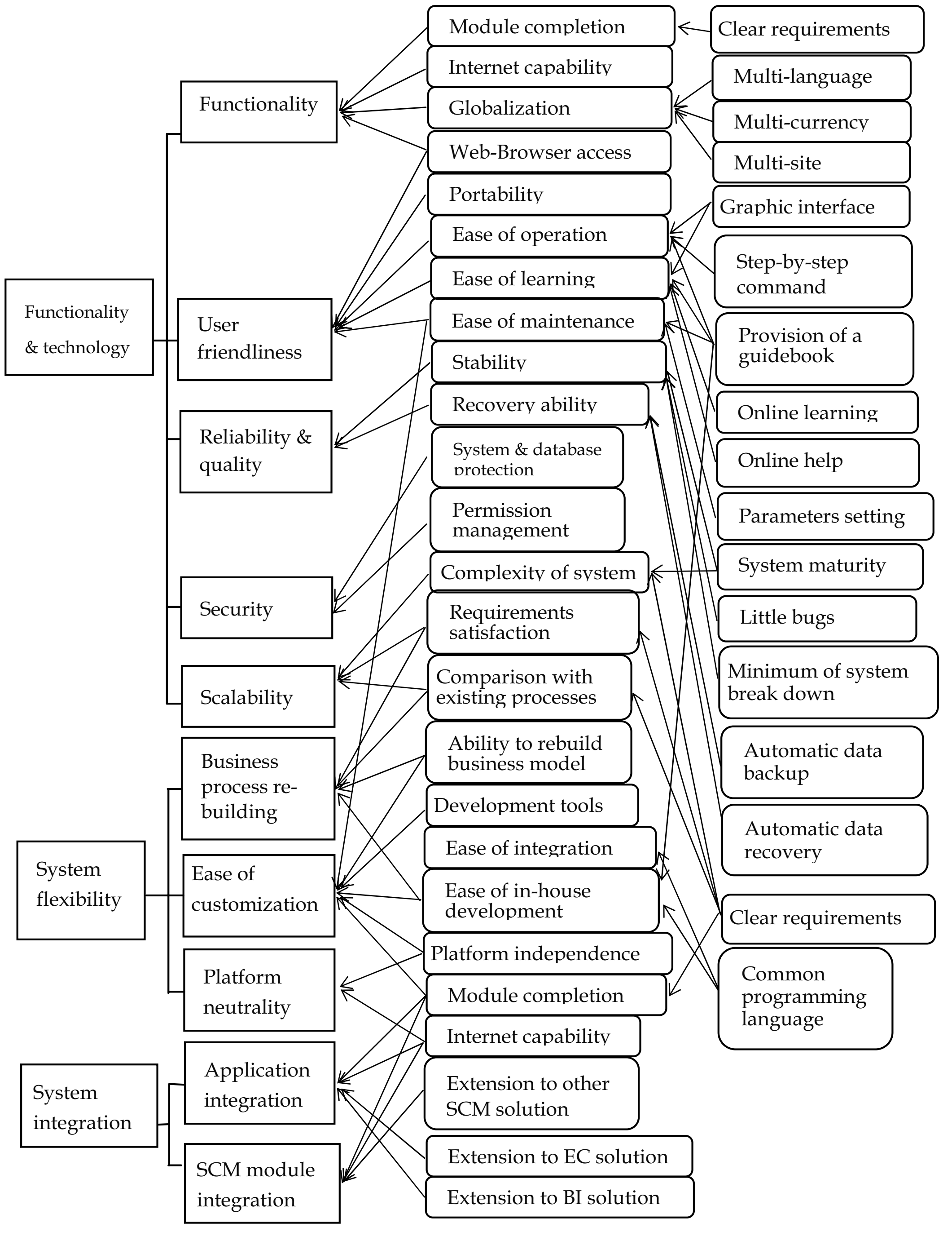

Figure 5. The means objective network of system factors

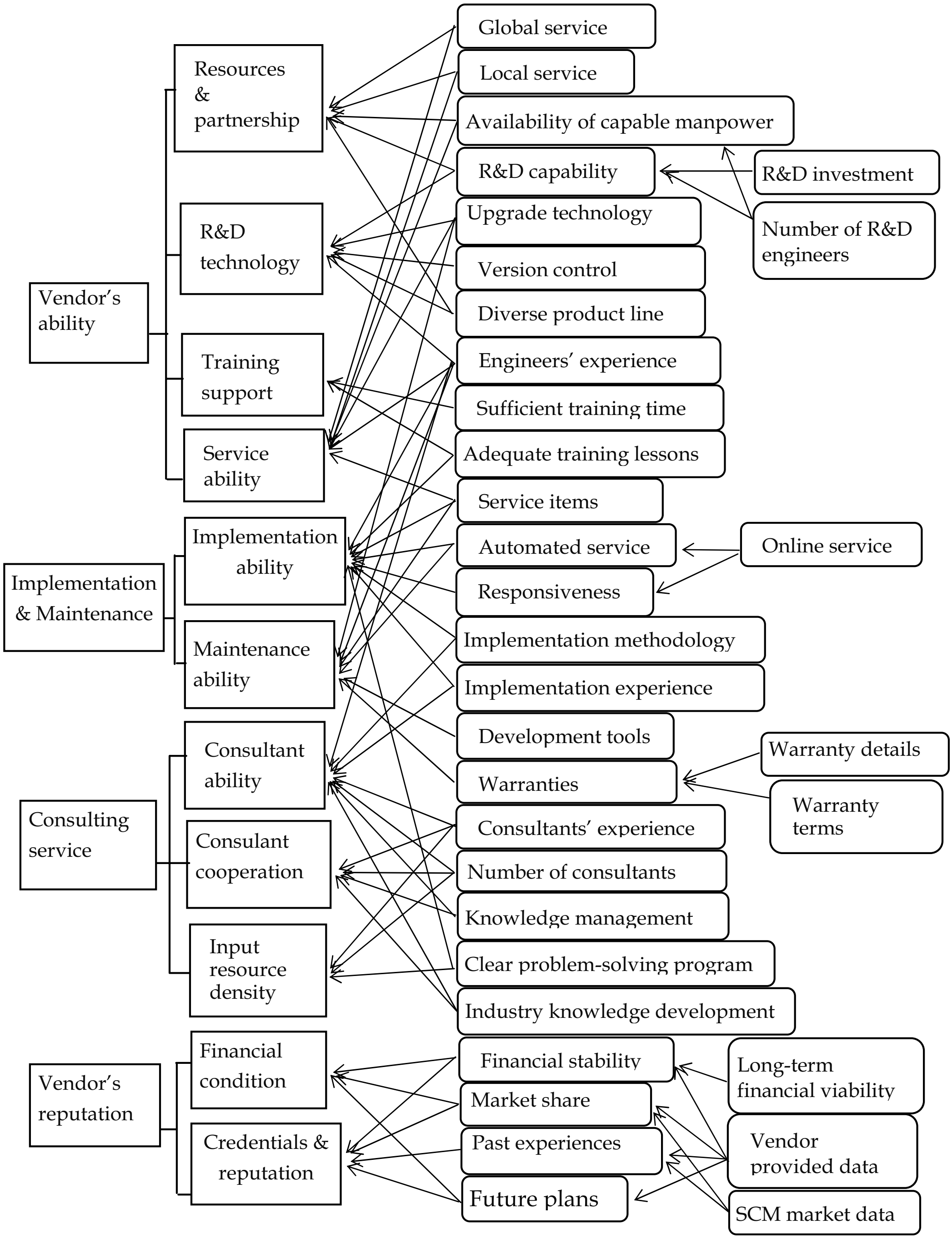

Figure 6. The means objective network of vendor factors

concluded that the system can provide complete modules, has good Internet capability, support global operations, offer Web-Browser access, and satisfy the requirements of existing processes. Futhermore, if they wanted to attain the means objective, module completion, they needed to recognize and offer clear requirements about the SCM system. Following similar approach, we systematically elaborated the cause–effect relationships among all the means objectives into a complete network. Similarly, the project team incorporated other means objectives into the network in a logical way. Also, the project team repeatedly examined all means objective linkages in order to confirm every relationship was reasonable. The process was iterative and diagnostic.

Step 5. The fundamental objective hierarchy was translated and modified to generate an attribute hierarchy for evaluating various SCM systems. In Fig. 4, level 3 consists of the main attributes that are used to measure various SCM systems and vendors. Level 4 contains the sub-attributes of some main attributes. Using the means objective network, the project team established the evaluation criteria and specific requirements. This process can ensure that everyone follows the same criteria in the evaluation process consistently.

Step 6. Information about SCM systems and vendors were widely surveyed from industry magazines, exhibitions, the Internet, and yearbook. Unfavorable alternatives were eliminated by asking the listed vendors a few questions, which were formulated according to the means objective network. After preliminary screening, three vendors PA, PB, and PC, were remained for further evaluation. Intensive interviews and meetings were scheduled with each vendor. Core business flow and special features were assessed by running demo scenarios and examining the capacity of each system to fulfill key demands. Finally, user representatives conducted unit tests to evaluate system feasibility.

Step 7. The company evaluated the three SCM alternatives using the fuzzy multi-attribute decision-making method. Readers can refer to Wei et al. (2007). After the decision makers' quantitative and qualitative assessing and methematical aggregating, the ranking order was P_A, P_B, and P_C. The most suitable SCM project was P_A. The project team thus recommended SCM system P_A as the most suitable selection for the company.

5. Conclusion

In this chapter, we proposed a framework to select an adequate SCM system based on the decision-analysis process. By the proposed procedures, the company can identify the elements of SCM project selection problem and formulate the fundamental objectives hierarchy and means objectives network, which are aligned with the goals and strategies of the company. The pertinent attributes for evaluating a variety of SCM systems and vendors can be derived according to these objectives structures. Some suggested attributes also were introduced.

The development process of the SCM fundamental objectives and means objectives are the most critical step in a SCM system selection project. The objective development method can fit to any quantitative and qualitative decision-making method. Additionally, the objectives structure of SCM selection can be developed and refined by the decision analysis process. The method can fully reflects the decision makers' cognition, the requirements of company, and the proper direction to achieve the objectives, even if the project team does not use any quantitative evaluation method.

In addition, using the proposed framework is very flexible to accommodate additional attributes or new decision maker in the evaluation. It is found that the framework can reduce the time taken to obtain the consensus of multiple decision makers.

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8

Impact of Hybrid Business Models in the Supply Chain Performance

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1. Introduction

Today's manufacturing competition goes beyond single companies and becomes a battle fought between supply chains (Min, 2002), (Nyoman, 2004), meaning the focus has changed from the local manufacturing company to the international supply chain (Olhager, 2003), (Ismail, 2006). In this scenario, competitiveness becomes something holistic about the total supply chain system rather than just what the company entity at the end of the supply chain can offer (Duclos, 2003). Moreover, the service provided to the end customer is determined by the effectiveness and efficiency of the cooperation of all the companies in the supply chain (Terzi, 2004). This trend demands organizations to improve and optimize their supply chain strategies, in order to respond and satisfy customers' demands (Sen, 2004), i.e. to provide end users with the right product at the right place, time, and price (Griffiths, 2000). As the degree of interaction between the members of the supply chain depends on the type of business models used by them (Browne, 1999), the fulfillment of the customer's demands can be achieved through the use of different business models (Sen, 2004). A business model answers who the customer is and what the customer wants, so value can be delivered at an appropriate cost (Chung, 2004). Ngai (2005) offers a value chain-based classification of the different business models used in a supply chain environment: engineer-to-order (ETO), make-to-order (MTO), assembly-to-order (ATO), make-to-stock (MTS), and ship-to-stock (STS). Each typical business model has its advantages and limitations, and only fits for some certain supply chain scenarios (Wadhwa, 2002).

1.1 Hybrid business models

According to Li (2001), a poor supply chain performance can be attributed to a mismatch between the intended market and the business model used to address it. From here the premise that nature of business models must be dynamic: as the current level of competition puts pressure to shift from sales market to customer market (Vonderembse, 2006), a response to a changing market environment (i.e. the market changes in terms of how products win orders in the market place), requires shifting between business models (Olhager, 2003). As this last is not a trivial task, in practice organizations have opted to use hybrid business models. Sen (2004) recognizes the fact that business models cannot be crisply classified as A or B, and that most of the time the complexity of real-life business

environments force supply chains to use hybrid business models. These hybrid business models are the result of serial/horizontal integration or parallel/vertical integration. In the first case, companies within the supply chain adopt either business model A or business model B, in series. In the second case, companies within the supply chain adopt business model A and business model B, in parallel and in some proportion.
Next section reviews the literature in the area of hybrid business models, while in section three, a quantitative model is offered. In section four, the quantitative model is used to evaluate the influence of these hybrid business models on the performance of the supply chain. Finally, section five presents conclusions and future research.

2. Literature review

Several authors have worked in the past, in the area of business models: Fogarty (1991) called them production positioning strategies, Oden (1993) considered them as methods of response to customer demand, and Hendry (1999) proposed a classification of them. Regarding the use of business models, Hax (1984) proposed customer service and total cost as the criteria to decide between MTS and MTO business models. Hendry (1989) compared MTO and MTS environments with regard to production planning techniques. Guerrero (1991) focused on ATO environments on which component parts are produced according to the forecast demand and assembled into final products based on actual demand. Fumero (1994) proposed a hierarchical planning approach for companies using the ATO business model. Handfield (1995) developed a framework for analyzing time-based strategies in MTO environments. Bilas (1996) discussed the production scheduling in MTO and ATO environments. Caputo (1996) outlined various types of buffers for MTO environments with various types of demand. Dellaert (1996) focused on the lot-sizing problem in a MTO environment. Bridleman (1997) discussed supply chain management and scheduling in MTO environments. Federgruen (1999) dealt with the problem of stochastic economic lot scheduling in mixed MTO and MTS environments. Rajagopalan (2002) provides a heuristic procedure to solve the problem of batch sizes for MTO–MTS environments. Tsubone (2002) states that even though changes in market demand requires organizations to operate under both MTO and MTS environments, there are few studies on the systematic combination of both: authors like Samadhi (1995), Sipper (1997), and Vollman (1997) discuss the differences between them, authors like Williams (1984), Kogan (1998), Nguyen (1998), and New (1995) focus on the issues of combining them, and Soman (2004) presents an elaborate literature review of combined MTO–MTS situations. In general, the main limitation of the past research is that it has focused on improving one business model, or comparing business models to see which performs better under certain circumstances, but have not paid much attention on the integration of business models. Two authors that have addressed this last issue are Li (1999, 2001) and Sen (2004). Next section reviews their work and relates it to our research proposal.

3. Model proposal

In order to evaluate the influence of hybrid business models on the performance of the supply chain, a simulation model was derived (and tested under different operational conditions). We limited our model building effort to the parallel/vertical integration of the MTO and MTS business models.

When market uncertainty is high (in terms of quantity and timing), a MTO business model (where production planning is made on actual orders rather than on forecast) is recommended (Safizadeh, 1997). An MTO business model allows to eliminate finished goods inventories and reduces the firm's exposure to financial risk - as production is initiated until a customer order is received - but usually spells long customer lead times and large order backlogs (Gupta, 2004). As the risk of stockpiling based on un-accurate sales forecasting is avoided by completely precluding building up anticipation stocks, a chase strategy can be used, where the expected demand is tracked and the corresponding capacity is computed, raising it or lowering it accordingly (Buxey, 2003). Safizadeh (1997) suggested that when following a chase strategy, a job shop should be used. A job shop uses general-purpose equipment and a multi-skilled work force (grouped around the process), which provides a high degree of flexibility and capability that allows the profitable manufacturing of low-volumes of customized products. Because of this last is that Li (2001) refers to this business model as a market responsive strategy.
When market uncertainty is low (in terms of quantity and timing), a MTS business model (where production planning is made on forecast rather than on actual orders) is recommended (Safizadeh, 1997). An MTS business model allows to compete in response time - as production of a low variety of stable products is made ahead of demand, kept in stock, and shipped upon receipt of orders (meaning little or no order backlog) - but becomes a) costly, when the number of products is large; and b) risky, when demand is highly variable and/or products have short life cycles (Gupta, 2004). As the reliability of the sales forecasts (and the low variety of stable product produced) reduces the chance of creating obsolete products, a level strategy can be used, where a steady production is maintained and finished goods (smoothing/anticipation) stocks are used to absorb ongoing differences between output and sales (Buxey, 2003). Safizadeh (1997) suggested that when following a level strategy, a continuous production line should be used. A continuous production line uses automated, special-purpose equipment (grouped around the product), which provides a high degree of efficiency and consistent quality that allows the profitable manufacturing of high-volumes of standardized products. Because of this last is that Li (2001) refers to this business model as a physically efficient strategy.
Note: in agreement with Sen (2004), we consider the ATO business model to be essentially the combination of the MTS and MTO environments; i.e. a limited and known variety of products are stocked in a ready-to-assemble condition and assembled to meet the orders. For this reason, the ATO business model is not considered for the hybrid business model analysis.

3.1 Integration ratio X

In order to represent the degree of parallel/vertical integration of these two models, in this paper we introduce the concept of the integration ratio X. Li (1999, 2001) considers the expected lead time (ELT) and stock level carrying cost (ESC) of a company, to be dependent on the materials procurement, production, and distribution lead times (SL and PL) and the type of business model used (denoted by the values taken by the variables qsl and qpl shown in Table 1). In order for Table 1 to make sense, the ELT must be understood as an equivalent to the response time, as proposed by Yucesan (2000), the time between the reception of a customer order and the time of delivery:

- In MTO environments, response time is virtually equal to the lead time (assuming that the time between the order receipt and production authorization is negligible).
- In MTS environments, response time is no longer the same as the lead time. Response time can be improved (over lead time), by holding inventory.

ELT =	qsl*SL + qpl*PL
qsl, qpl =>	Type of business model: MTO or MTS
SL =>	lead time from supplier
PL =>	lead time from production
for MTO, ELT =	SL + PL
and,	qsl = 1, qpl = 1
for MTS, ELT =	0 + 0
and,	qsl = 0, qpl = 0

Table 1. Expected lead time of a company using MTO and MTS business models, adapted from Li (2001).

On the other hand, Sen (2004) considers the expected inventory cost (TEI) of an N-partners supply chain, to be dependent on the type of business model used by each partner (denoted by the yn% proportion of MTS and 1- yn% proportion of MTO in Table 2).

TEI =	$\sum_{n=1}^{n=N}$ yn% * MEIn * bn * T
yn% =>	proportion of MTS business model
MEIn =>	mean expected inventory at nth partner
Bn =>	inventory cost per unit at nth partner
T =>	time period of planning
for MTS, yn% =	1
for MTO, yn% =	0

Table 2. Expected inventory cost of a supply chain using hybrid business models, adapted from Sen (2004).

When qsl, qpl, and yn% are compared, we notice that they play a similar role in the description of the hybrid business model. In this paper we retake this idea, and propose to represent the business model proportionality through the use of an integration ratio *X*. It must be noted that neither Li or Sen offers an explanation of the meaning of the business model proportionality. In our case, the integration ratio *X* can be understood as an indicator of the level of customer feedback and therefore, of the uncertainty of what to do next, when to do it, and for how long, as shown in Table 3: when the integration ratio *X* = 1, then the hybrid business model is a pure MTO and all the activities are driven by customer's information (the uncertainty of what, when, and for how long is at its maximum, so a waiting time for instruction is required and no planning ahead of time – like building inventory - can take place); when the integration ratio *X* = 0, then the hybrid business model is a pure MTS and all the activities are driven by forecast information (the uncertainty of what, when, and for how long is at its minimum, so a waiting time for instruction is not required and planning ahead of time – like building inventory - can take place). This reasoning is consistent with the formulas in Tables 1 and 2.

SUBCYCLES	ACTIVITIES	S1 = info from customer; S2 = info from forecast	
		MTO	MTS
Supply	Make versus buy decisions	S1	S2
	Identify, evaluate, and develop suppliers	S1	S2
	Negotiate terms for quantity, quality, delivery, and price	S1	S2
	Release orders for materials, and components	S1	S2
	Release orders for tooling	S1	S2
	Monitor suppliers to ensure compliance with terms	S1	S2
Production	Production planning and control	S1	S2
	Materials management	S1	S2
	Fabricate parts	S1	S2
	Assemble products	S1	S2
	Inspection, testing, rework	S1	S2
	Inventory finished products	N/A	S2
Distribution	Ship products to distribution center	N/A	S2
	Pick products for customer orders	S1	S2
	Ship products and invoice customers	S1	S1

Table 3. Source of customer feedback for MTO and MTS business models, adapted from Miltenburg (1996).

3.2 Simulation model structure

The analyzed supply chain is linear, with four partners serially connected, and with partner i using and hybrid business model that is X_i percentage of MTO (Figure 1). Two are the supply chain performance criteria: total response time (given by the sum of the response times of partner i during period j of the planning period T), and total backlog (given by the accumulated backlog of partner 1, at the end of planning period T).

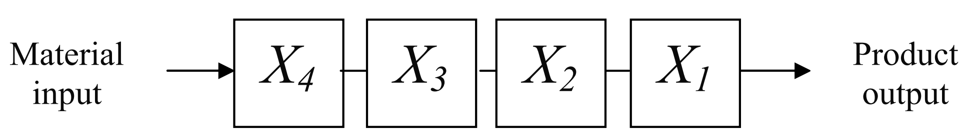

Figure 1. The serial supply chain with hybrid business models

The main differences between our proposal and Li's and Sen's work are the following:

- Li's work mainly focus on analyzing the cost/time impact of MTO, ATO, and MTS as standalone business models and not part of a supply chain (as we propose).
- Sen's work mainly focus on the cost impact of hybrid business model within a supply chain, but not the time and inventory impact (as we propose).

For the purpose of quantitatively analyzing the impact of various degrees of business model integration ratios on the supply chain performance (i.e. total response time, total backlog), a systems dynamics (SD) simulation model was built - using the simulation software iThink (1996) – and used to test a series of different scenarios. SD is a system thinking approach that a) is not data driven, b) targets the top management levels, and c) focuses on how the structure of a system and the taken policies affect its behavior (Eskandari, 2007). For this reason, the SD model presented in this paper can be considered a second order model - in contrast to first order models that are used for theory testing (Larsen, 2002) - a research instrument for theory development rather than a tool for assisting decision-making (Adamides, 2006). The simulation model was verified and validated following a similar approach to the one in Hwarng (2005): the model was presented to experienced professionals in the area of simulation model building, the simulation model output was examined for reasonableness under a variety of settings of input parameters, i.e. the lead times of each supply chain partner were set to some known deterministic value, and later the simulation model output was compared with manual calculations (finding no discrepancies between the simulation and manual calculations). Figure 2 shows the SD simulation model. The most important assumptions made in the simulation model are the following:

- *Backlog* P_i is the difference between *demand* P_i and *supply* P_i, during period j of the planning period T.
- *Demand* P_i varies according to a normal distribution, with a mean of 100 units and a standard deviation of *uncertainty* $_i$. The normal distribution is used to represent a symmetrically variation above and below a mean value (Banks, 2000).
- *Uncertainty* $_i$ ranges from 0 (low) to 20 (high).
- *Demand* P_i is transmitted without distortion to supply chain partner P_{i+i}. This means that *demand* $P_1 = P_2 = P_3 = P_4$.
- Supply P_i is equal to supply P_i OUT.
- Supply P_i OUT is equal to Supply P_i IN after a delay of lead time P_i.
- *Lead time* P_i varies according to a normal distribution (see Table 4). Lead time is given in weeks.
- *Supply* P_i *IN* is the sum of the contribution made by *inventory* P_i and *capacity* P_i. This is done with the intention to reflect the different demand fulfillment strategies, i.e. level strategy (inventory-oriented) for MTS environments and chase strategy (capacity-oriented) for MTO environments.
- *Business model* P_i ranges from 0 (MTS environment) to 1 (MTO environment).
- *Inventory* P_i is equal to:

$$\text{supply } P_{i+1} * (1 - \text{business model } P_i) * (1 - (\text{uncertainty }_i / 20))$$

In this way, when *uncertainty* $_i$ is low (0) and *business model* P_i is 0 (MTS environment), all the contribution to *supply* P_i *IN* comes from *inventory* P_i (as established by a level strategy), and is equal to the input from *supply* P_{i+1}.

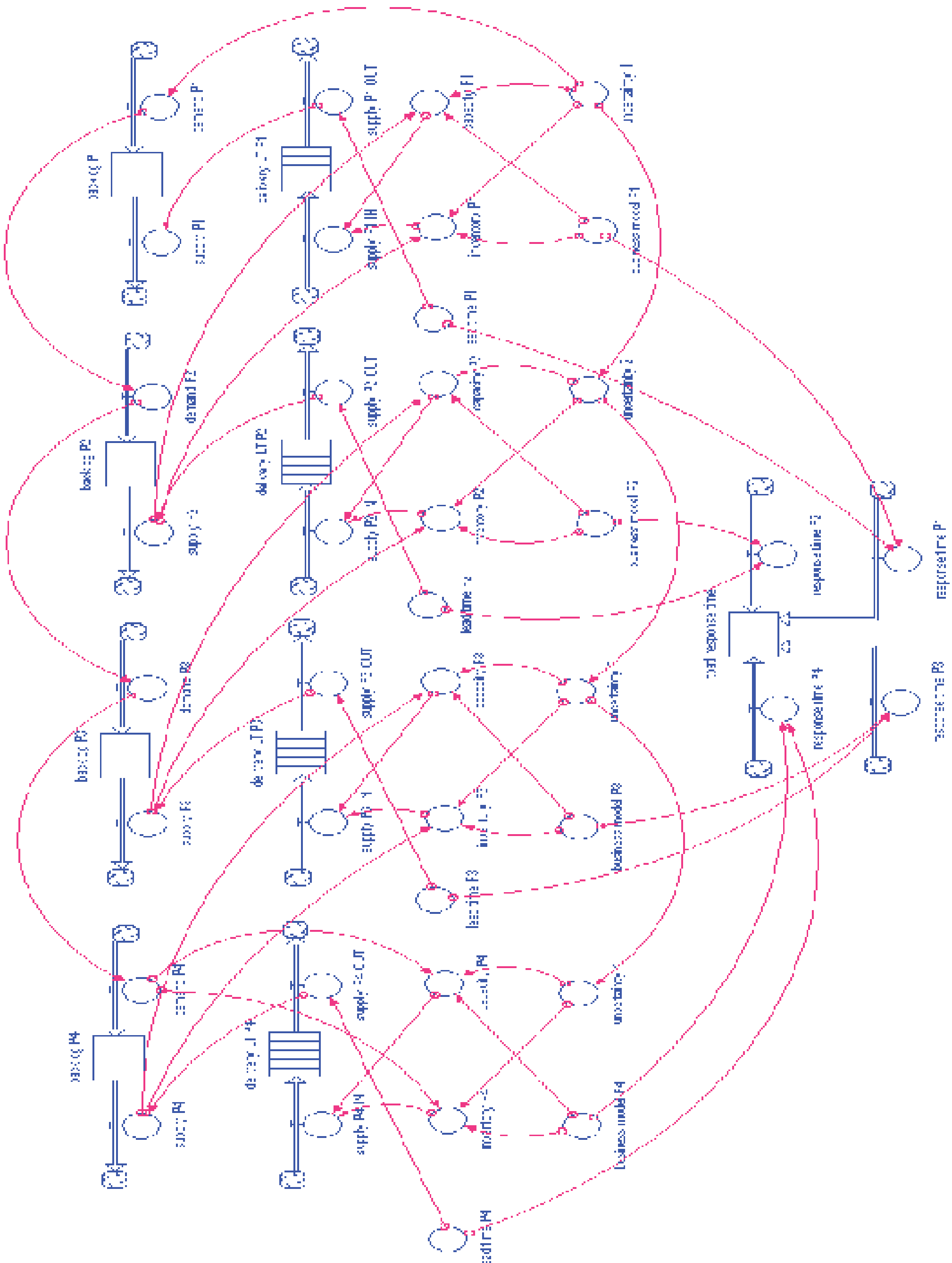

Figure 2. SD simulation model of the serial supply chain with hybrid business models

- Capacity Pi is equal to:

$$\text{supply } P_{i+1} * (\text{business model } P_i) * (\text{ uncertainty }_i / 20)$$

In this way, when *uncertainty* $_i$ is high (1) and *business model* P_i is 1 (MTO environment), all the contribution to *supply* P_i *IN* comes from *capacity* P_i (as established by a chase strategy), and is equal to the input from *supply* P_{i+1}.

- Response time P_i is equal to:

$$\text{lead time } P_i * \text{business model } P_i$$

In this way, when *business model* P_i is 1 (MTO environment), the response time is equal to the lead time (as established in section 3.1).

4. Sensitivity analysis

Experiments consisted of testing several scenarios to collect statistical data on the supply chain TT. Initially, 414 different scenarios were tested (with planning period T = 30) and 30 replications per scenario were used to build confidence intervals of 95% level. The rest of this section analyzes the results presented on Tables 6 through 13. The scenarios tested were:

- The effect of varying the level of demand uncertainty and lead time variation (Table 4).
- The effect of varying *X* and the number of partners using the *X* conditions (Table 5).

Demand variation	**P1**	**P2**	**P3**	**P4**
Scenario 1: high variation	100 + Normal (0, 20)			
Scenario 2: medium variation	100 + Normal (0, 10)			
Scenario 3: low variation	100 + Normal (0, 0)			
Lead time variation	**P1**	**P2**	**P3**	**P4**
Scenario 1: low variation	Normal (2, 0)	Normal (1, 0)	Normal (5, 0)	Normal (3, 0)
Scenario 2: medium variation	Normal (2, 0.25)	Normal (1, 0.25)	Normal (5, 0.25)	Normal (3,0.25)
Scenario 3: high variation	Normal (2, 0.5)	Normal (1, 0.5)	Normal (5, 0.5)	Normal (3, 0)

Table 4. Mean values of the supply chain operational conditions

Combinations	Compossitions			
	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**
1	P1P2P3P4	N/A	N/A	N/A
2	P1P2P3	P4	P4	P4
3	P1P2P4	P3	P3	P3
4	P1P3P4	P2	P2	P2
5	P2P3P4	P1	P1	P1
6	P1P2	P3P4	P3P4	P3P4
7	P1P3	P2P4	P2P4	P2P4
8	P1P4	P2P3	P2P3	P2P3
9	P2P3	P1P4	P1P4	P1P4
10	P2P4	P1P3	P1P3	P1P3
11	P3P4	P1P2	P1P2	P1P2
12	P1	P2P3P4	P2P3P4	P2P3P4
13	P2	P1P3P4	P1P3P4	P1P3P4
14	P3	P1P2P4	P1P2P4	P1P2P4
15	P4	P1P2P3	P1P2P3	P1P2P3
16	N/A	P1P2P3P4	P1P2P3P4	P1P2P3P4

Table 5. Supply chain combinations and compositions

4.1 Simulation results: lead time variation analysis

For scenarios 1-3 and combinations 1-16, as *X* decreases (left to right), the total response time values decrease (see Table 6). This is because each partner's hybrid business model tends to be a pure MTS, where all the activities are driven by forecast information. For scenarios 1-3, highest total response time values are found:

- For combinations 2-5, when P2 decreases its *X* (combination 4).
- For combinations 6-11, when P1 and P2 decrease their *X* (combination 11).
- For combinations 12-15, when P1, P2, and P4 decrease their *X* (combination 14).

This can be explained as follows: P2 and P1 have the first and second shortest lead time values (Table 5), so reducing them have a low impact on the total response time value.

- For scenarios 1-3, lowest total response time values are found: For combinations 2-5, when P3 decreases its *X* (combination 3).
- For combinations 6-11, when P3 and P4 decrease their *X* (combination 6).
- For combinations 12-15, when P1, P3, and P4 decrease their *X* (combination 13).

This can be explained as follows: P3 and P4 have the first and second largest lead time values (Table 5), so reducing them have a big impact on the total response time value.

Scenario 1: low lead time variation					**Scenario 2: medium lead time variation**					**Scenario 3: high lead time variation**				
Combination	**X = 1**	**X = 0.6**	**X = 0.3**	**X = 0.0**	**Combination**	**X = 1**	**X = 0.6**	**X = 0.3**	**X = 0.0**	**Combination**	**X = 1**	**X = 0.6**	**X = 0.3**	**X = 0.0**
1	11	N/A	N/A	N/A	1	11.05	N/A	N/A	N/A	1	11.09	N/A	N/A	N/A
4	P1P3P4	10.6	10.3	10	4	P1P3P4	10.72	10.36	10.11	4	P1P3P4	10.68	10.14	9.97
5	P2P3P4	10.2	9.6	9	5	P2P3P4	10.27	9.68	8.89	5	P2P3P4	10.34	9.77	9.06
2	P1P2P3	9.8	8.9	8	2	P1P2P3	9.72	8.79	7.97	2	P1P2P3	9.68	8.90	7.91
3	P1P2P4	9	7.5	6	3	P1P2P4	8.22	7.36	5.94	3	P1P2P4	8.91	7.44	5.58
11	P3P4	9.8	8.9	8	11	P3P4	9.76	9.06	7.94	11	P3P4	9.71	8.93	7.78
7	P1P3	9.4	8.2	7	7	P1P3	9.42	8.36	6.99	7	P1P3	9.33	8.41	6.83
9	P2P3	9	7.5	6	9	P2P3	8.85	7.52	5.99	9	P2P3	9.01	7.54	5.92
8	P1P4	8.6	6.8	5	8	P1P4	8.50	6.81	5.05	8	P1P4	8.21	6.82	5.00
10	P2P4	8.2	6.1	4	10	P2P4	8.19	6.16	3.98	10	P2P4	8.10	6.25	3.96
6	P1P2	7.8	5.4	3	6	P1P2	7.76	5.31	3.06	6	P1P2	7.78	5.44	2.88
14	P3	8.6	6.8	5	14	P3	8.49	6.78	5.17	14	P3	8.76	6.76	4.90
15	P4	7.8	5.4	3	15	P4	7.86	5.39	2.98	15	P4	7.74	5.47	2.86
12	P1	7.4	4.7	2	12	P1	7.33	4.96	1.96	12	P1	7.26	4.73	1.95
13	P2	7	4	1	13	P2	7.03	4.04	1.05	13	P2	7.17	3.96	1.14
16	N/A	6.6	3.3	0	16	N/A	6.75	3.39	0	16	N/A	6.51	3.35	0

	Higher values		Lower values

Table 6. Total response time

When compared the total response time values of scenarios 1, 2, and 3, we found that (see Table 7):

- As uncertainty increases (scenarios 1 vs. scenario 2 vs. scenario 3) more MTO-oriented hybrid business models should be preferred by the supply chain partners, as they allow the market responsive strategy required by the unpredictability of the firms' environment. We can see how as the uncertainty increases and the number of partners using a pure MTO business model decreases, the % of time shorter response time values are found also decreases.

	Lead time variation variation	
Combination	**Medium (Scenario 2)**	**High (Scenario 3)**
1	0	0
2-5	58.33	66.66
6-11	55.55	61.11
12-15	50	58.33
16	0	50

Table 7. Percentage of time lower total response time values are found, when compared to scenario 1 (low lead time variation)

			FREQUENCY OF:											
			COMBINATIONS					**SCENARIOS**			**X**			
Response time value	**Frecuency**	**%**	**1**	**2-5**	**6-11**	**12-15**	**16**	**L_{LT}**	**M_{LT}**	**H_{LT}**	**1**	**0.6**	**0.3**	**0.0**
11+	3	2.15	1					1	1	1	3			
10-11	11	7.91		2				4	4	3		6	3	2
9-10	20	14.38		4	3			6	5	6		13	4	3
8-9	23	16.54		3	5	1		5	8	7		10	9	4
7-8	22	15.82		2	4	3		3	6	8		12	6	4
6-7	17	12.23		1	4	1	1	6	5	5		3	9	4
5-6	15	10.79		1	3	2		4	6	5			6	9
4-5	7	5.03			1	3		3	2	2			5	2
3-4	9	6.47			2	2	1	3	3	3			4	5
2-3	4	2.87			1	3		1	1	2				4
1-2	5	3.59				2		1	2	2				5
0-1	3	2.15					1	1	1	3				3
Frecuency %			1.75	22.80	40.35	29.82	5.26	29.45	34.10	36.43	2.17	31.88	33.33	32.60

Table 8. Total response time, ordered from higher to lower values

When ordered the total response time values, from higher to lower values (Table 8), we notice that:

- The response time values in the brackets of 8-9 weeks and 7-8 weeks are the first and second place in frequency (16.54% and 15.82%).

- Combinations 6-11 are the most frequent (40.35%) and heavily influence the response time values in the 8-9 and 7-8 brackets.
- Scenario 3 (high lead time variation) is the most frequent (36.43%), and heavily influences the response time values in the 8-9 and 7-8 brackets.
- Integration ratio X = 0.3 is the most frequent (33.33%) and heavily influences the response time values in the 8-9 and 7-8 brackets.

From these results, it can be concluded that the same results (in terms of total response time values) can be achieved by allowing the supply chain partners to manage their operations on their own way without imposing a specific business model. For example, by having at most two supply chain partners using a pure MTO business model (i.e. combinations 6-11) and allowing the rest of the partners to operate under certain conditions (i.e. composition X = 0.3), the uncertainty present in the system (high lead time variation, scenario 3) can be handled in a way that the total response time value can be reduced up to 36.36% (from 11+ weeks to 7 weeks).

4.2 Simulation results: demand variation analysis

For scenarios 1-2, combinations 1-16, and low to high lead time variation, as X decreases (left to right), the total backlog values increase (Tables 9, 10, and 11). This is because each partner's hybrid business model tends to be a pure MTS, where a level strategy (inventory-oriented) is followed (not the most appropriate when demand uncertainty is present).

In the case of scenario 3, combinations 1-15, and low to high lead time variation, as X decreases (left to right), the total backlog value remains the same (3000). This is because as long as there is one supply chain partner (using a pure MTO business model) in a low demand uncertainty environment, its contribution to the backlog downstream the supply chain will be zero (see the expression for *Capacity* P_i, in section 3.2). The value of 3000 is then the result of 100 units per period j during a planning period T = 30.

In the case of scenario 3, combination 16, and low to high lead time variation, as X decreases (left to right), the total backlog value decrease. This is because in a low demand uncertainty environment, a level strategy (inventory-oriented) performs better than a chase strategy (capacity-oriented). For scenarios 1-2, and low to high lead time variation, highest total backlog values are found:

- For combinations 2-5, when P3 decreases its X (combination 3).
- For combinations 6-11, when P3 and P4 decrease their X (combination 6).
- For combinations 12-15, when P1, P3, and P4 decrease their X (combination 13).

This can be explained as follows: as stated before, in environments where demand uncertainty is present, as each partner's hybrid business model tends to be a pure MTS (X decreasing), the total backlog value increases because the level strategy (inventory-oriented) followed is not the most appropriate. If we take into account that P3 and P4 have the first and second largest lead time values (Table 5), this increasing effect (on the total backlog value) lasts longer. The opposite is observed for scenarios 1-2, and low to high lead time variation, where the lowest total backlog values are found:

- For combinations 2-5, when P2 decreases its X (combination 4).
- For combinations 6-11, when P1 and P2 decrease their X (combination 11).
- For combinations 12-15, when P1, P2, and P4 decrease their X (combination 14).

Scenario 1: high demand variation					Scenario 2: medium demand variation					Scenario 3: low demand variation				
Combination	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**	**Combination**	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**	**Combination**	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**
1	1080.8	N/A	N/A	N/A	1	2925.8	N/A	N/A	N/A	1	3000	N/A	N/A	N/A
3	P1P2P4	1841.23	2561.95	3052.77	3	P1P2P4	2940.74	2974.09	2979.82	3	P1P2P4	3000	3000	3000
2	P1P2P3	1782.13	2440.25	3031.86	2	P1P2P3	2930.15	2963.02	2965.43	2	P1P2P3	3000	3000	3000
5	P2P3P4	1779.91	2374.54	3022.3	5	P2P3P4	2864.1	2877.72	2948.52	5	P2P3P4	3000	3000	3000
4	P1P3P4	1752.52	2348.79	2907.12	4	P1P3P4	2822.42	2851.88	2879.43	4	P1P3P4	3000	3000	3000
6	P1P2	2390.14	2973.91	3124.48	6	P1P2	2934.41	2992.09	3129.19	6	P1P2	3000	3000	3000
10	P2P4	2367.28	2927.9	3074.45	10	P2P4	2901.65	2949.65	3093.2	10	P2P4	3000	3000	3000
8	P1P4	2361.47	2885.11	3008.49	8	P1P4	2865.19	2923.08	2993.01	8	P1P4	3000	3000	3000
9	P2P3	2358.58	2875.96	2997.03	9	P2P3	2861.16	2880.68	2960.43	9	P2P3	3000	3000	3000
7	P1P3	2325.07	2858.14	2949.11	7	P1P3	2765.64	2851.98	2900.25	7	P1P3	3000	3000	3000
11	P3P4	2205.9	2838.58	2928.76	11	P3P4	2690.14	2773.79	2888.25	11	P3P4	3000	3000	3000
13	P2	2724.79	2970.61	3170.36	13	P2	2899.68	3015.26	3036.74	13	P2	3000	3000	3000
12	P1	2696.9	2913.99	3097.95	12	P1	2872.73	2881.96	2898.16	12	P1	3000	3000	3000
15	P4	2635.31	2905.54	3066.75	15	P4	2867.91	2874.32	2887.1	15	P4	3000	3000	3000
14	P3	2576.37	2873.72	3030.06	14	P3	2847.76	2866.05	2882.96	14	P3	3000	3000	3000
16	N/A	2737.35	2989.16	3151.41	16	N/A	2838.06	2866.27	2870.32	16	N/A	2951.4	2543.8	1100

Higher values	Lower values

Table 9. Total backlog, low lead time variation

Scenario 1: high demand variation					Scenario 2: medium demand variation					Scenario 3: low demand variation				
Combination	X = 1	X = 0.6	X = 0.3	X = 0.0	**Combination**	X = 1	X = 0.6	X = 0.3	X = 0.0	**Combination**	X = 1	X = 0.6	X = 0.3	X = 0.0
1	1006.5	N/A	N/A	N/A	1	2948.5	N/A	N/A	N/A	1	3000	N/A	N/A	N/A
3	P1P2P4	1918.53	2368.22	3066.3	3	P1P2P4	2956.49	2986.23	3120.53	3	P1P2P4	3000	3000	3000
2	P1P2P3	1908.07	2366.52	3005.25	2	P1P2P3	2917.79	2977.29	2993.22	2	P1P2P3	3000	3000	3000
5	P2P3P4	1766.97	2335.81	2998.61	5	P2P3P4	2889.98	2904.11	2970.48	5	P2P3P4	3000	3000	3000
4	P1P3P4	1752.37	2292.75	2745.44	4	P1P3P4	2779.37	2893.02	2937.61	4	P1P3P4	3000	3000	3000
6	P1P2	2432.95	2933.35	3064.35	6	P1P2	2883.91	2961.17	3082.81	6	P1P2	3000	3000	3000
10	P2P4	2356.86	2894.33	3028.69	10	P2P4	2844.13	2901.58	3039.58	10	P2P4	3000	3000	3000
8	P1P4	2274.22	2875.29	2947.94	8	P1P4	2814.26	2898.11	2924.77	8	P1P4	3000	3000	3000
9	P2P3	2212.64	2850.64	2930.69	9	P2P3	2814.01	2893.23	2921.52	9	P2P3	3000	3000	3000
7	P1P3	2202.15	2812.8	2911.94	7	P1P3	2803.85	2805.04	2900.05	7	P1P3	3000	3000	3000
11	P3P4	2097.17	2778.84	2906.48	11	P3P4	2752.19	2768.07	2863.77	11	P3P4	3000	3000	3000
13	P2	2696.47	2932.79	3223.23	13	P2	2899.88	2982.19	3028.82	13	P2	3000	3000	3000
12	P1	2635.7	2917.14	3203.85	12	P1	2859.02	2926.09	2942.66	12	P1	3000	3000	3000
15	P4	2621.63	2891.91	3064.13	15	P4	2850.35	2883.97	2893.97	15	P4	3000	3000	3000
14	P3	2579.89	2879.55	2982.3	14	P3	2844.3	2871.43	2888.72	14	P3	3000	3000	3000
16	N/A	2728.46	3092.83	3121.16	16	N/A	2873.69	2910.99	2959.37	16	N/A	2951.4	2543.8	1100

Higher values | Lower values

Table 10. Total backlog, medium lead time variation

Scenario 1: high demand variation					Scenario 2: medium demand variation					Scenario 3: low demand variation				
Combination	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**	**Combination**	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**	**Combination**	X = **1**	X = **0.6**	X = **0.3**	X = **0.0**
1	1170.3	N/A	N/A	N/A	1	2918.4	N/A	N/A	N/A	1	3000	N/A	N/A	N/A
3	P1P2P4	1986.17	2540.96	3082.34	3	P1P2P4	2927.17	2947.6	3101.93	3	P1P2P4	3000	3000	3000
2	P1P2P3	1828.18	2457.84	2957.05	2	P1P2P3	2841.95	2932.1	3018.21	2	P1P2P3	3000	3000	3000
5	P2P3P4	1798.92	2453.21	2943.69	5	P2P3P4	2840.24	2919.5	2932.2	5	P2P3P4	3000	3000	3000
4	P1P3P4	1791.96	2387.85	2909.54	4	P1P3P4	2819.95	2835.5	2861.37	4	P1P3P4	3000	3000	3000
6	P1P2	2418.87	2961.09	3085.43	6	P1P2	2921.01	3089.2	3096.44	6	P1P2	3000	3000	3000
10	P2P4	2380.29	2897.14	3064.43	10	P2P4	2887.96	2954.2	2984.96	10	P2P4	3000	3000	3000
8	P1P4	2371.82	2885.71	3036.18	8	P1P4	2868.81	2937.3	2980.81	8	P1P4	3000	3000	3000
9	P2P3	2333.06	2850.06	2986.75	9	P2P3	2830.17	2905.9	2942.19	9	P2P3	3000	3000	3000
7	P1P3	2303.92	2842.92	2962.46	7	P1P3	2763.5	2875	2906.44	7	P1P3	3000	3000	3000
11	P3P4	2265.1	2799.69	2891.18	11	P3P4	2749.52	2794.9	2874.44	11	P3P4	3000	3000	3000
13	P2	2693.96	2945.65	3131.87	13	P2	2939.11	3027.4	3209.06	13	P2	3000	3000	3000
12	P1	2657.68	2919.53	3073.6	12	P1	2870.83	2970.9	2927.15	12	P1	3000	3000	3000
15	P4	2544.8	2896.29	2979.34	15	P4	2850.02	2888.5	2922.7	15	P4	3000	3000	3000
14	P3	2415.43	2871.72	2946.77	14	P3	2845.29	2871.4	2875.52	14	P3	3000	3000	3000
16	N/A	2651.8	2961.52	3088.74	16	N/A	2900.06	2945.7	2946.74	16	N/A	2951.4	2543.8	1100

Higher values	Lower values

Table 11. Total backlog, high lead time variation

In this case, P2 and P1 have the first and second shortest lead time values (Table 5), so their increasing effect (on the total backlog value) don’t last much. When compared the total backlog values of scenarios 1, 2, and 3, and low lead time variation, we found two things (see Table 12):

- Regarding demand variation; as uncertainty decreases (scenarios 1 vs. scenario 2 vs. scenario 3) more MTS-oriented hybrid business models should be preferred by the supply chain partners, as they allow the physically efficient strategy fitted for a forecast-driven environment. We can see how as the uncertainty decreases, and the number of partners using a pure MTS business model increases, the % of time lower total backlog values are found also increases.
- Regarding lead time variation; as uncertainty increases (Table 9 vs. Table 10 vs. Table 11) more MTO-oriented hybrid business models should be preferred by the supply chain partners, as they allow the market responsive strategy required by the unpredictability of the firms’ environment. We can see how as the uncertainty increases and the number of partners using a pure MTO business decreases (i.e., combination 2-5 of Table 9 vs. combination 2-5 of Table 10 vs. combination 2-5 of Table 11), the % of time lower total backlog values found also decreases (or remain the same).

Lead time variation		**Demand variation**	
	Combination	**Medium (Scenario 2)**	**Low (Scenario 3)**
Low (Table 9)	1	0	0
	2-5	33.33	25
	6-11	33.33	16.66
	12-15	58.33	33.33
	16	66.66	66.66
Médium (Table 10)	1	0	0
	2-5	25	16.66
	6-11	33.33	16.66
	12-15	50	25
	16	66.66	66.66
High (Table 11)	1	0	0
	2-5	16.66	8.33
	6-11	33.33	16.66
	12-15	41.66	16.66
	16	66.66	66.66

Table 12. Percentage of time lower total backlog values are found, when compared to scenario 1 (high demand variation)

When ordered the total backlog values, from higher to lower values (Table 13), we notice that:

- The total backlog values in the brackets of 3000+ and 2800-3000 units are the first and second place in frequency (41.16% and 39.95%).
- Combinations 6-11 are the most frequent (37.28%) and heavily influence the total backlog values in the 3000+ and 2800-3000 brackets..

Backlog value	Frecuency	%	FREQUENCY OF:														
			COMBINATIONS					SCENARIOS						X			
			1	**2-5**	**6-11**	**12-15**	**16**	L_D	M_D	H_D	L_{LT}	M_{LT}	H_{LT}	**1**	**0.6**	**0.3**	**0.0**
3000+	170	41.16	3	47	60	58	2	129	14	27	1	1	1	3	43	45	79
2800-3000	165	39.95	3	37	66	48	11	3	114	48	1	1	1	3	40	76	46
2600-2800	23	5.56		2	11	8	2		9	14	1	1	1		17	5	1
2400-2600	14	3.38		6	1	4	3	3		11	1	1	1		6	8	
2200-2400	23	5.56		7	15					22	1	1	1		15	7	
2000-2200	0	0													1		
1800-2000	4	0.96		4						4	1	1	1		4		
1600-1800	7	1.69		7						7	1	1	1		7		
1400-1600	0	0															
1200-1400	0	0															
1000-1200	7	1.69	2	2			3	3		4	1	1	1	3	1		3
Frecuency %			**1.93**	**27.11**	**37.28**	**28.57**	**5.08**	**33.74**	**33.49**	**32.76**	**33.33**	**33.33**	**33.33**	**2.17**	**32.44**	**34.14**	**31.23**

Table 13. Total backlog, ordered from higher to lower values

- Scenarios 1, 2, and 3 (low, medium, and high demand variation) influence equally (33.74%, 33.49%, and 32.76%) the total backlog values in the 3000+ and 2800-3000 brackets.
- Scenarios 1, 2, and 3 (low, medium, and high demand variation) influence equally (33.33%, 33.33%, and 33.33%) the total backlog values in the 3000+ and 2800-3000 brackets..
- Integration ratio X = 0.3 is the most frequent (34.14%) and heavily influences the total backlog values in the 3000+ and 2800-3000 brackets

When these results are compared to those of Table 8, we notice that combinations 6-11 and integration ratio X = 0.3 heavily influence both the most frequent response time values (the 8-9 and 7-8 brackets, Table 8) and the most frequent total backlog values (the 3000+ and 2800-3000 brackets, Table 13). This shows that there is a trade off between total response time and total backlog: the MTO-based portion of the supply chain allows the handling of the uncertainty present in such way that the total response time value can be reduced. However, the MTS-based portion of the supply chain causes the total backlog value increases because the level strategy (inventory-oriented) followed is not the most appropriate when uncertainty is present in the system.

5. Conclusions

The international supply chain (SC) is the way to compete in today's market. The business model used by the SC members must be dynamic in order to respond to changes in the customers' demands, at an appropriate cost. For this reason is that in practice, SC members have opted to use hybrid business models. The objective of this chapter was to quantitatively evaluate the influence these hybrid business models have on the performance of the supply chain. For this purpose, a systems dynamics (SD) simulation model was built and used to test a series of different scenarios (i.e. the effect of varying the level of demand uncertainty and lead time variation, and the effect of varying the business model integration ratio). Statistical data was collected regarding two performance criteria (i.e. total response time and total backlog). Some of the findings include:

- For high lead time uncertainty environments, MTO-oriented hybrid business models should be preferred by the supply chain partners (in order to obtain shorter response time values).
- For low demand uncertainty environments, MTS-oriented hybrid business models should be preferred by the supply chain partners (in order to obtain lower total backlog values).
- Allowing the supply chain partners to manage their operations on their own way - without imposing a specific business model – allows the achievement of the same total response time results.
- There is a trade off between total response time and total backlog. The MTO-based portion of the supply chain allows shorter response time values, while the MTS-based portion of the supply chain causes the total backlog values to increase.
- A proper combination of MTO-based and MTS-based SC partners allows the achievement of balanced results in both SC performance criteria.

As a conclusion we can say that the operation of the SC (as a whole) is greatly impacted by the individual configuration decisions (i.e. degree of hybrid business model used) of the SC partners, and that depending on the chosen SC performance criteria (i.e. total response time or total backlog), different arrangements should be preferred. This research effort acknowledges that several elements need to be incorporated into the SD simulation model in order to be considered a realistic one. For this reason, future research will address the balance between global (whole SC) and individual benefits (SC partners); the SC performance at the chain level and the operations level; the impact of varying the level of product standardization and process flexibility of each SC partner; the impact of demand distortion from SC partner to SC partner; and the impact of different lead time ratios among SC partners.

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Configuring Multi-Stage Global Supply Chains with Uncertain Demand

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1. Introduction

Global outsourcing has emerged as one of the major approaches for many industries to gain competitive edge. The movement of the domestic supply chains towards globalization involves the company's worldwide interests and necessitates a unified way of managing and coordinating activities all across the globe.

As the result of globalization, research in global supply chains is receiving more and more attention and many studies have been conducted to tackle various features associated with global networks. In this chapter we focus on the configuration of the global supply chains facing uncertain demand. We specifically intend to coordinate the supplier selection with global production-distribution decisions such as the determination of the capacity of each manufacturing facility and the material flow between different facilities.

Based on the literature review an issue that has not received enough attention in this research area is the uncertainty factor. Schmidt & Wilhelm (2000) and Santoso *et al.* (2004) mention that few studies have addressed the uncertainties associated with global networks. Uncertainties are integral parts of global companies and failing to incorporate these factors in any model trying to tackle global supply chain problems might result in great financial losses or even failure of the business.

The policy for selecting suppliers is one of the most crucial decisions which affects both the quality and cost of the products, especially in IT and manufacturing industries. There are a vast number of emerging small and medium-sized enterprises especially in Asia which are selected everyday to serve as major outsourcing targets due to their lower labor and material costs. Only a few researches in the global context focus on the capacitated supplier selection issues under demand uncertainty and combining the supplier selection issue with global production-distribution decisions is an important feature of our model, Qi (2007).

In global supply chain management it is very important to consider the overall costs of the network. While labor and production costs may be significantly lower across the border companies must also consider other factors such as exchange and tariff rates, costs of space, governmental considerations and global trade issues. The proposed model considers the

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exchange and tariff rates which are one of the deciding factors in selecting the most appropriate locations across the globe for investments or choosing the right outsourcing partners.
A two-stage stochastic programming method is employed to solve the stochastic problem and the scenario-based approach is used to model the uncertain variables. A mixed-integer linear program is developed to formulate the whole problem and it is finally applied to do some sensitivity analyses in order to obtain managerial insights.
The rest of the chapter is organized as follows: Section 2 presents the literature review. Section 3 introduces the two-stage stochastic programming method. Examples and numerical results are discussed in Section 4 and the last section concludes our work.

2. Literature review

The reviewed literature has been divided into three main categories: supplier selection under demand uncertainty, stochastic supply chain design and global supply chain design.

2.1 Supplier selection under demand uncertainty

There is a growing interest in research on the supplier selection under demand uncertainty. Kim *et al*. (2002) investigated how to configure a supply network with uncertain consumer demands for multiple products. They then analyzed the Lagrangian relaxation and optimality conditions of the problem and finally developed an iterative algorithm to solve the model.
Alonso-Ayuso (2003) presented a two-stage stochastic 0-1 model for supply chain management under uncertainty in order to determine the production topology, plant sizing, product selection, product allocation among the plants and the vendor selection for raw materials.
Shu *et al*. (2005) studied the stochastic transportation-inventory network design problem consisting of one supplier and multiple retailers facing uncertain demand. The problem involves the allocation of retailers to distribution centres and is formulated as a set-covering integer programming model.
Qi (2007) studied an integrated decision making model that takes into account the price-sensitive demand and multiple capacitated suppliers. Zhang & Ma (2007) considered both demand uncertainty and quantity discount in acquisition policies for a supply network involving one manufacturer and multiple suppliers, both subject to capacity limitations.

2.2 Stochastic supply chain design

There exist several stochastic factors in today's supply chains. Most of the researches that address the uncertainties use two distinct approaches: probabilistic approach or scenario planning approach. The choice of the most appropriate strategy is very dependant on the context and the extent of available data, Zimmermann (2000). Two-stage stochastic programming method is an approach which is widely used in the literature, Cheung *et al* (1996), Mirhassani *et al* (2000), Tsiakis *et al* (2001), Gupta & Maranas (2000) and (2003), Chen *et al* (2004), Santoso *et al* (2004) and Guillén *et al* (2005).
Gupta & Maranas (2000) and (2003), propose a two-stage stochastic programming approach for incorporating demand uncertainty in multi-site midterm supply chain planning

problems, adopting the midterm planning model of McDonald & Karimi (1997) as the reference model. The inner optimization problem is solved by obtaining its closed-form solution using linear programming (LP) duality. The extension of this work is to account for a general probability distribution and to incorporate the uncertainty in revenue, transportation and penalty costs.

Tsiakis *et al*. (2001) consider the design of a multi-product, multi-echelon supply chain and determine the capacity and location decisions. They consider economies of scale in transportation costs and use the two-stage stochastic programming method assuming only three possible scenarios to model the uncertainty in demand.

Fewer researches address multiple objectives in their model. Typical objectives besides cost minimization and profit maximization are fair profit distribution, safe inventory levels, and maximum customer service level, Chen et al (2004) and Guillén et al (2005).

2.3 Global supply chain design

Recently there has been significant work done in domestic supply chain design and facility location problems under both deterministic and stochastic conditions. Fewer researches have focused on the supply chains operating under international conditions such as exchange and tariff rates, governmental regulations etc.

Hodder & Jucker (1985) tackle the international plant location problem under price and exchange rate uncertainty for a mean-variance decision maker. They redefine the profit maximizing objective function using the decision maker’s risk aversion coefficient and provide an analytical framework to solve the mixed-integer quadratic programming problem. The objective is maximizing the profit under deterministic conditions. The paper does not consider the different stages in global supply chains.

Transfer price is the price that a selling department, division, or subsidiary of a company charges for a product or service supplied to a buying department, division, or subsidiary of the same firm, Abdallah (1989). Goetschalckx *et al* (2002) demonstrate the savings potential generated by the integration of the design of strategic global supply chain networks, with the determination of tactical production–distribution allocations and transfer prices. They mention that transfer pricing is one of the most important issues today’s multinational companies face.

Mohamed (1999) proposes a model that considers production and logistics decisions for multinational companies .The decisions made are sensitive to inflation and exchange rates, capacity levels and the efficiency of the plants. It does not consider the stochasticity in demand or in other factors involved in multinational environments and considers only the minimization of costs as an objective. Bhutta *et al*. (2003) extend the previously published models on multinational facility location problems and incorporate production, distribution and investment decisions. The model does not consider the uncertainties present in multinational environments.

A comprehensive literature review on strategic, tactical and operational aspects of international logistics networks is presented by Schmidt & Wilhelm (2000). They discuss the relevant modeling issues for each of the aspects and mention that few studies have addressed the uncertainties associated with tactical aspects of the global logistics networks. They mention that there is the need for an approach that unifies all the three planning levels coupled with efficient solution approaches that can solve realistic instances of the models.

Meixell *et al*. (2005) review the decision support models for the design of global supply chains. They mention that although most models tackle a difficult feature associated with globalization, few models address the practical global supply chain design. As a future research they recommend considering multi-tier supply chains with internal production sites and external suppliers, more performance criteria and a wider variety of industries.

A group of global supply chain models address the relevant issues and considerations for the business environment under NAFTA, Bookbinder & Fox (1998), Wilhelm *et al* (2005) and Robinson & Bookbinder (2007). Bookbinder & Fox (1998) obtain the optimal routings for intermodal containerized transport from Canada to Mexico with the associated transportation costs for two transportation modes and the respecting lead-times. In another recent work, Robinson & Bookbinder (2007) formulate and solve a mixed-integer programming model to find the optimal supply chain for a real world problem of a Canadian manufacturer of power supplies.

3. Multi-stage global supply chains design with uncertain demand

Consider a global supply network that consists of suppliers, manufacturing facilities, distribution centres and customer (retail) zones. We assume that the decisions on the selection of manufacturing facilities, distribution centres and suppliers and also delivery to customer zones are all controlled by a centralized manufacturer. The objective of the problem is to configure the whole supply network so that the expected total cost is minimized considering the target demand satisfaction level.

Stochastic customer demand can be met from any distribution centre via different transportation modes. Depending on the lost sale and overstocking costs and penalties, type and importance of the products and customers or other policies or considerations the company might pursue, different target service levels or transportation modes with longer or shorter lead-times might be selected.

Our model allows expansion over the maximum available capacity at each facility. This feature of the model captures the tradeoffs between capacity expansion and moving production to the facilities with higher available capacity.

We assume that there is not enough available information about the probability distributions of the demand but based on historical data several scenarios with known probabilities can be generated which help model the uncertainties using the scenario-based approach.

The two-stage stochastic programming method is used to formulate the stochastic problem. In the proposed model the supplier selection, production and capacity expansion decisions are first-stage decisions which are made prior to the demand realization, whereas distribution decisions to the customer zones are second-stage variables which are postponed until the uncertain variable is realized.

The network studied in this work consists of h domestic suppliers, g international suppliers, m domestic manufacturing facilities, n international manufacturing facilities, d distribution centres and c customer zones. As the result there will be $(h+g+m+n+d+c)$ nodes in the network. We use the notation given in Appendix A to develop our model. We will first discuss the terms in the objective function and then the model constraints.

3.1 Objective function

The overall objective of the problem is the minimization of costs and maximization of the customer expected average service level. As previously mentioned the focus should be on minimizing the *overall* costs since moving directly to the locations with the lower costs is not always the best case and several other tradeoffs should be considered in order to make the most appropriate decisions.

The solution of the multi-objective problem consists of a set of Pareto optimal global network configurations which is obtained by the - ε constraint method, Haimes *et al* (1971). Based on this method the minimization of the total cost is kept as the main objective function and maximization of the expected average service level is added as a constraint to the model, bounded by some feasible ε. Different levels of ε generate the entire Pareto optimal set, Guillén et al (2005). We seek to find the maximum allowable ε until the decision maker is satisfied with the level of service. In the scenario-based approach the uncertainty is captured in terms of several discrete realization scenarios of the stochastic variables. The objective is to find the best solution under all scenarios which minimizes the total cost of the first-stage variables plus the expected cost of the second-stage variables with respect to the minimum accepted service level.

We consider three demand realizations scenarios: high, medium and low, to capture optimistic, likely and pessimistic possible outcomes of the demand for each customer zone. This leads to $N_{js} = 3^c$ joint demand scenarios with their corresponding probabilities, where c is the total number of customer zones. We assume the probability of the occurrence of each individual scenario s for each customer is known, thus the probability of the occurrence of the joint scenarios js, can be easily calculated. It should be noted that the decision variables with superscript s correspond to the second-stage stochastic variables and the joint probabilities will satisfy:

$$\sum_{js=1}^{N_{js}} \xi_{js} = 1 \cdot \tag{1}$$

In the following sections we formulate each of the cost components that are involved in the supply network and the related constraints.

3.1.1 Raw material cost

The total purchasing costs of raw material is determined by the supplier selection decision and then the raw material allocation among the suppliers:

$$RC = \sum_{i=1}^{I} \sum_{j=1}^{h} \sum_{k=h+g+1}^{h+g+m} \sum_{t} c_{ijk} x_{ijkt} + \sum_{i=1}^{I} \sum_{j=h+1}^{h+g} \sum_{k=h+g+m+1}^{h+g+m+n} \sum_{t} c_{ijk} x_{ijkt} \; . \tag{2}$$

The first term is the total raw material cost for the domestic plants and the second term corresponds to the same cost for the international plants. Without loss of generality we assume that the plants only procure raw materials from the local suppliers within the same country.

3.1.2 Production cost

Economies of scale are present in production costs. For each of the manufacturing facilities the production amount is divided into NR_j sub-ranges each corresponding to a lower unit production cost. The total production cost is modeld as a piecewise linear function of the production amount as shown in Figure 1. In order to calculate the total production costs at domestic plants we introduce the binary variable V_{jpt}, which defines the range the production amount belongs to:

$$V_{jpt} = \begin{cases} 1, \text{ if } Q_{jt} \in \left[\overline{Q}_{p-1}, \overline{Q}_p\right] \\ 0, \text{ otherwise.} \end{cases}$$

In order to ensure that the production amount belongs to only one sub-range we use the following constraint:

$$\sum_{p=1}^{NR_j} V_{jpt} \leq 1 \qquad \forall t, j = h+g+1, ..., h+g+m \cdot \tag{3}$$

The production amount is then modeld as:

$$\overline{Q}_{p-1} V_{jpt} \leq Q_{jpt} \leq \overline{Q}_p V_{jpt} \qquad \forall t, p = 1, ..., NR_j, j = h+g+1, ...h+g+m, \tag{4}$$

$$Q_{jt} = \sum_{p=1}^{NR_j} Q_{jpt} \qquad \forall t, j = h+g+1, ..., h+g+m \cdot \tag{5}$$

Finally the total production cost at the domestic plants is calculated as:

$$PC = \sum_{j=h+g+1}^{h+g+m} \sum_t \sum_{p=1}^{NR_j} \left[\overline{UPC}_{p-1} V_{jpt} + (Q_{jpt} - \overline{Q}_{p-1} V_{jpt}) \frac{\overline{UPC}_p - \overline{UPC}_{p-1}}{\overline{Q}_p - \overline{Q}_{p-1}} \right]. \tag{6}$$

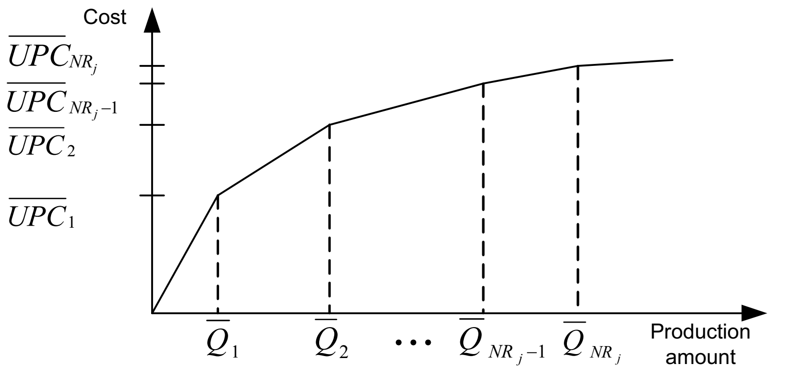

Figure 1. Economies of scale in production cost

We take the same procedure to calculate the total production costs at international plants considering the exchange rate factor:

$$PCI=\sum_{j=h+g+m+1}^{h+g+m+n}\sum_{t}\frac{1}{E_{jt}}\sum_{p=1}^{NR_j}\left[\overline{UPC}_{p-1}V_{jpt}+(Q_{jpt}-\overline{Q}_{p-1}V_{jpt})\frac{\overline{UPC}_p-\overline{UPC}_{p-1}}{\overline{Q}_p-\overline{Q}_{p-1}}\right]. \tag{7}$$

3.1.3 Transportation cost

The transportation cost incurred at the plants and distribution centres is assumed to be proportional to the shipment amount with a constant unit transportation cost as well as the pipeline inventory cost, Robinson & Bookbinder (2007). The corresponding term in the objective function is of the following form:

$$TC=\sum_{j=h+g+1}^{h+g+m}\sum_{k=h+g+m+n+1}^{h+g+m+n+d}\sum_{r}\sum_{t}(UTC_{jkr}+PI\times LT_{jkr})Q_{jkrt}, \tag{8}$$

$$TCI=\sum_{j=h+g+m+1}^{h+g+m+n}\sum_{k=h+g+m+n+1}^{h+g+m+n+d}\sum_{r}\sum_{t}\frac{1}{E_{jt}}(UTC_{jkr}+PI\times LT_{jkr})Q_{jkrt}, \tag{9}$$

$$TCD=\sum_{j=h+g+m+n+1}^{h+g+m+n+d}\sum_{k=h+g+m+n+d+1}^{h+g+m+n+d+c}\sum_{r}\sum_{t}(UTC_{jkr}+PI\times LT_{jkr})Q_{jkrt}. \tag{10}$$

The raw material transportation cost is not considered in the model with the assumption that either it is already included the transportation costs or the supplier is responsible for delivering the raw materials to the manufacturing sites.

3.1.4 Capacity expansion cost

The model allows the expansion of capacity over the maximum amount of available resources but there is a limit for such expansion. Based on the chase strategy for aggregate planning we assume the capacity, such as the workforce, can be adjusted from period to period. Here the model decides between outsourcing the production to the international plants with greater capacity or expanding the existing capacity at the domestic plants. It is assumed that the capacity expansion cost is lower at international locations. The capacity expansion cost at the domestic and international plants is:

$$TCapCj=\sum_{j=h+g+1}^{h+g+m}\sum_{t}CapC_j\times max(0,Cap_{jt}-Cap\,max_j), \tag{11}$$

$$TCapCjI=\sum_{j=h+g+m+1}^{h+g+m+n}\sum_{t}\frac{1}{E_{jt}}\times CapC_j\times max(0,Cap_{jt}-Cap\,max_j). \tag{12}$$

To avoid the computational complexity of the above mentioned nonlinear constraints, we introduce the binary variable y_{jt} which shows if capacity expansion occurs at plant j in period t or not:

$$
\begin{aligned}
&y_{jt}Cap\max_j \le u_{1jt} \le y_{jt}M \ , \ \forall t, j = h+g+1,...,h+g+m \\
&0 \le u_{2jt} \le (1-y_{jt})Cap\max_j, \ \forall t, j = h+g+1,...,h+g+m \\
&Cap_{jt} = u_{1jt} + u_{2jt}, \ \forall t, j = h+g+1,...,h+g+m.
\end{aligned}
\tag{13}
$$

And the total capacity expansion costs will be calculated as follows:

$$
\begin{aligned}
&TCapC = \sum_{j=h+g+1}^{h+g+m} \sum_t CapC_j \times (u_{1jt} - Cap\max_j \times y_{jt}) \\
&+ \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \times CapC_j \times (u_{1jt} - Cap\max_j \times y_{jt}).
\end{aligned}
\tag{14}
$$

The above mentioned terms correspond to the capacity expansion costs for the domestic and international plants respectively.

3.1.5 Tariff cost

Countries impose various restrictions on products coming into their markets, sometimes in shape of tariff or import duties which is usually expressed as a percentage of the selling price or the manufacturing cost, Bhutta *et al* (2003). In our model tariff cost occurs whenever the production is outsourced to the international manufacturing facilities and is then shipped to the distribution centres in other countries. The tariff cost is expressed as a percentage of the total manufacturing costs incurred at the international plants. This percentage which expresses the tariff rates varies between each two different countries:

$$
TarC = \sum_{j=h+g+m+1}^{h+g+m+n} Tariff_j \sum_t \frac{1}{E_{jt}} \sum_{p=1}^{NR_j} \left[\overline{UPC}_{p-1} V_{jpt} + (Q_{jpt} - \overline{Q}_{p-1} V_{jpt}) \frac{\overline{UPC}_p - \overline{UPC}_{p-1}}{\overline{Q}_p - \overline{Q}_{p-1}} \right]. \tag{15}
$$

3.1.6 Inventory cost

Inventory costs at the manufacturing and distribution facilities are assumed to be proportional to the amount kept in inventory with respect to the unit inventory cost:

$$
IC = \sum_{j=h+g+1}^{h+g+m} \sum_t UIC_j \times I_{jt} + \sum_{j=h+g+m+1}^{h+g+m+n} \sum_t \frac{1}{E_{jt}} \times UIC_j \times I_{jt} + \sum_{j=h+g+m+n+1}^{h+g+m+n+d} \sum_t UIC_j \times I_{jt} \cdot \tag{16}
$$

3.1.7 Expected lost sale and overstock cost

The expected lost sale and overstock amounts are second-stage variables and the associated costs under each joint scenario are calculated with respect to their penalties. This gives the decision maker the flexibility to adjust the service level and the probability of meeting the demand for each customer zone individually. The decision variables with superscript s correspond to the second-stage stochastic variables:

$$
\sum_{js=1}^{N_{js}} \xi_{js} \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_t \left[LC \times LostSale_{l,t,js}^s + OC \times Overstock_{l,t,js}^s \right]. \tag{17}
$$

The objective function of minimizing the overall costs is developed by the summation of all the previously discussed costs.

3.2 Constraints

In this section we explain the problem constraints. The capacity of the manufacturing facilities at both domestic and international locations should be at least equal to the production amount at the facilities. This allows the production amount exceed the maximum available capacity at each facility at the expense of incurring capacity expansion costs:

$$Q_{jt} \le Cap_{jt} \qquad \forall t, j = h+g+1,\dots,h+g+m+n. \tag{18}$$

We impose the resource constraints for the suppliers to ensure that the amount of resource required for supplier j to produce a certain number of raw materials is within its resource capacity:

$$\sum_{i=1}^{I}\sum_{k=h+g+1}^{h+g+m}\beta_{ij}x_{ijkt} \le q_j \qquad \forall t, j = 1,\dots,h, \tag{19a}$$

$$\sum_{i=1}^{I}\sum_{k=h+g+m+1}^{h+g+m+n}\beta_{ij}x_{ijkt} \le q_j \qquad \forall t, j = h+1,\dots,h+g. \tag{19b}$$

Raw material requirement constraints are to ensure there are sufficient raw materials for the production planning in the period t:

$$\alpha_i Q_{kt} \le \sum_{j=1}^{h} x_{ijkt} \qquad \forall t, i, k = h+g+1,\dots h+g+m, \tag{20a}$$

$$\alpha_i Q_{kt} \le \sum_{j=h+1}^{h+g} x_{ijkt} \qquad \forall t, i, k = h+g+m+1,\dots h+g+m+n. \tag{20b}$$

The production level at each manufacturing plant in each period plus the remaining inventory level from the previous period must be equal to the total outgoing flow from each plant to all distribution centres via all transportation modes plus the excess inventory which is carried over to the following periods:

$$Q_{jt} + I_{j,t-1} = \sum_{k=h+g+m+n+1}^{h+g+m+n+d}\sum_{r} Q_{jkrt} + I_{jt} \qquad \forall t, j = h+g+1,\dots,g+h+m+n. \tag{21}$$

If the initial inventory levels at the manufacturing and distribution facilities are assumed to be zero, the customer demand might be lost for the initial planning periods, depending on the lead-times between different stages of the supply chain. Of course if the decision maker assumes initial inventories at the manufacturing facilities the service level will improve:

$$I_{j,0} = 0 \qquad \forall t, j = g+h+1,\dots,g+h+m+n+d \tag{22}$$

The total amount each distribution centre ships to the customer zones via all transportation modes plus the excess inventory carried over to the following periods should be equal to the sum of the amount received from all the domestic and international facilities by all transportation modes considering the associated lead-times, plus the remaining inventory from the previous period:

$$\sum_{j=h+g+1}^{h+g+m+n} \sum_{r} Q_{jkr,t-LT_{jk}} + I_{k,t-1} = \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_{r} Q_{klrt} + I_{kt} \tag{23}$$

$$\forall t, k = h+g+m+n+1,...,h+g+m+n+d \cdot$$

The decision on expected sales, overstock and lost sale amounts which are second-stage variables is postponed until the realization of the stochastic variable; thus the amount shipped from the distribution centres to each customer zone via all transportation modes results in sales or overstocking based on the target service level under each joint scenario:

$$\sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_{r} Q_{klr,t-LT_{klr}} = Sales^{s}_{l,t,js} + Overstock^{s}_{l,t,js} \tag{24}$$

$$\forall t, js, l = h+g+m+n+d+1,...,h+g+m+n+d+c \cdot$$

The stochastic lost sale for each customer and time period is the difference between the stochastic demand and the stochastic sales under each joint scenario:

$$LostSale^{s}_{l,t,js} = demand^{s}_{l,js} - Sales^{s}_{l,t,js} \tag{25}$$

$$\forall t, js, l = h+g+m+n+d+1,...,h+g+m+n+d+c \cdot$$

The stochastic sales to each customer can not exceed the total amount shipped to the customers or each customer stochastic demand. Under each joint scenario and time period if the realized demand is smaller than the shipped amount, the stochastic sales can not exceed the demand and if the realized demand is greater than the shipped amount, the stochastic sales can not exceed the shipped amount:

$$Sales^{s}_{l,t,js} \leq min(demand^{s}_{l,js}, \sum_{k=h+g+m+n+1}^{h+g+m+n+d} \sum_{r} Q_{klr,t-LT_{klr}}) \tag{26}$$

$$\forall t, js, l = h+g+m+n+d+1,...,h+g+m+n+d+c \cdot$$

Using the ε - constraint method, the objective of maximizing the expected service level has been added to the problem constraints bounded by the minimum accepted expected service level ε. The demand is uncertain and in order to define the production and transportation levels, the expected average service level is used as a measure in order to give the decision maker the ability of setting the company policies in terms of the extent of meeting the demand for each specific customer. The expected average service level is defined as the expected sales over the expected demand, Chen *et al* (2004) and Guillén *et al* (2005). The expected sale is a second-stage decision variable:

$$ASL = \frac{1}{c \times T} \sum_{l=h+g+m+n+d+1}^{h+g+m+n+d+c} \sum_{t} \frac{\sum_{js} \xi_{js} \times Sales^{s}_{l,t,js}}{\sum_{js} \xi_{js} \times demand^{s}_{l,js}} \geq \varepsilon \ . \tag{27}$$

Finally all we present the non-negativity and binary constraints:

$$V_{jpt} \in \{0,1\}, \tag{28}$$

$$y_{jt} \in \{0,1\}, \tag{29}$$

$$\text{all variables} \geq 0\,. \tag{30}$$

4. Experimental design

4.1 Model assumptions

In order to study the applicability of the proposed model we have considered a hypothetical network setting. The network addresses a Canadian company which has three manufacturing plants in Toronto, Calgary and Montreal and two distribution centres in Vancouver and Toronto. The main customer zones are Toronto, Halifax, Seattle, Chicago and Los Angeles. The company has the option of outsourcing its production to three candidate manufacturing plants in Mexico in Monterrey, Mexico City and Guadalajara and distributing through two candidate distribution centres in the US in Los Angeles and Houston. Of course any country can be selected based on the respecting exchange and tariff rates.

We consider three transportation modes of rail, truck and a combination of the two transportation modes. Again any transportation mode can be adopted in our model based on the cost and lead-time of each mode. We consider a single product without specifying its type as our main goal is to keep our model general so that it can be easily suited to different situations. The tool to adjust the proposed model to different supply chain and product types are the target service level, transportation mode selection with shorter or longer lead-times and the possibility of overstocking or losing the customer order. Our model is one of the few practical models which can be conveniently customized for various real world supply chains.

We have made some assumptions throughout the cases studied in this chapter. First of all we only consider tactical level decisions and the size of the facilities are small enough that can be either used or not at each planning period meaning that there is no long-term contract or ownership of the facilities. There is no restriction on the number of facilities serving each distribution centre or customer zone. Finally border crossing costs are assumed to be included in the transportation costs form international facilities to different destinations

Most of the input data on the transportation costs, transportation modes and the associated lead-times have been derived from Bookbinder & Fox (1998). The suppliers and raw

materials related information and data has been taken from the first example of Kim *et al*. (2002).
It should be noted that in general all the studied cases are hypothetical and based on the input parameters and assumption of zero initial inventory, lost sale and overstock levels. It is assumed in the model that the production, capacity expansion and inventory costs are lower at international locations.

4.2 Numerical example and cases

We assume that the manager of the above mentioned hypothetical company wants to decide on the expansion of its existing facilities or outsourcing to the potential international plants. We consider three general cases and then present our results and observations: 1) in the first base case we assume that the company has the option of outsourcing its production to international manufacturing facilities, 2) in the second case it is assumed that the entire manufacturing is outsourced and thus there is no in-house production and 3) in the third case it is assumed that all the production should be done domestically. All the cases are studied in 12 planning periods which is sufficient in order to maintain feasibility with respect to the transportation lead-times.

4.3 Observations

The problem has been modeled in AMPL and solved by CPLEX optimization software. The comparison of the results of the three cases in terms of the objective function values and different costs is given in Table 1 and Table 2.

Case	Total Cost	% Change in total cost	Maximum possible service level	% Change in service level	95% Maximum Service level	Total Cost	% Decrease in total cost
I. Base case	3892307.95	N/A	90.9%	N/A	86.3%	3591397.94	7.73%
II. Full outsourcing	5193925.01	33.4% increase	65.5%	14.6% decrease	62.2%	4923506.84	5.21%
III. No outsourcing	4161147.32	6.9% increase	90.9%	Same	86.3%	3829202.5	7.98%

Table 1. Comparison of the objective function values

According to the results in Table 1, both cases I and III have the same maximum possible service level while case I has the lowest total costs. Case II incurs the highest total costs and lowest service level. The solution in Table 1 also indicates that the total cost can be reduced as much as 7.98% if the service level is reduced to 95% of the maximum. The solution suggests serving a large portion of the Canadian customers from Canadian distribution centres and also two of the three customer zones in Seattle and Chicago would be served from Vancouver and Toronto respectively. As the result when the company outsources the whole manufacturing to Mexico, despite the fact that manufacturing costs decrease by 91%, transportation and lost sale costs increase by 65%, 114%. The reason is that in order to serve the Canadian customers from international manufacturing facilities, products should be sent to Canadian distribution centres which results in much higher transportation costs comparing to the base case. Also due to the larger distances to the distribution centres the stochastic sales to the customers can not be done sooner than period 3 which results in the decrease in the expected average service level and complete lost sales in the first two periods.

Case	Total production cost	Total transportation cost	Total lost sale cost	Total overstock cost	Total raw material cost
I. Base case	97104.06	700800	508750	207500	1310260
II. Full outsourcing	8719.97	1159306	1087750	175000	927514
III. No outsourcing	123450	659370	508750	207500	1380510

Table 2. Comparison of the costs

5. Conclusion

In this chapter we presented an integrated optimization model to provide a decision support tool for managers. The logistic decisions consist of the determination of the suppliers and the capacity of each potential manufacturing facility, and also the optimization of the material flow among all the production, distribution and consumer zones in global supply chains with uncertain demand. The model is among the few models to date than can be conveniently customized to capture real world supply chains with different characteristics. A hypothetical example was given to assess whether it is better for a company to go global or to expand its existing facilities and it was shown that outsourcing the whole production to the countries with lowest production costs is not always the best case and failing to consider several other cost factors might lead to much higher overall costs and lower service levels. It was also concluded that even the supply chain configurations leading to lower costs are not always the most suitable settings and the managers should not ignore the tradeoffs between the cost and the other objectives such as the service level in our case.

Future expansions to our model can be the addition of more global factors to make it more realistic and also suggesting solution procedures to solve larger instances of the model.

Appendix A

Notation

Sets and indices

j, k, l	Nodes (domestic and international suppliers, plants, distribution centres, and customers) in the supply network
p	Production quantity range
s	Individual realization scenarios of the stochastic variable (low, medium, high)
js	Joint realization scenarios of the stochastic variables
r	Transportation modes
i	Raw materials
t	Time periods

Decision variables

x_{ijkt}	Quantity of raw material *i* purchased from supplier j for plant *k* in period *t*
Q_{jt}	Quantity of products produced at plant *j* in period *t*
Q_{jpt}	Quantity of products produced at range *p* at plant *j* in period *t*
Q_{jkrt}	Quantity of products shipped from node *j* to node *k* via mode *r* in period *t*
Cap_{jt}	Capacity level at plant *j* in period *t*
$u1_{jt}$	Capacity level at plant *j* in period *t* when capacity in expanded
$u2_{jt}$	Capacity level at plant *j* in period *t* when capacity in not expanded
I_{jt}	Ending inventory level at node *j* in period *t*
$Sales^{s}_{l,t,js}$	Stochastic sales to customer zone *l* in period t under joint scenario *js*
$Lostsale^{s}_{l,t,js}$	Stochastic lost sale at customer zone *l* in period *t* under joint scenario *js*
$Overstock^{s}_{l,t,js}$	Stochastic overstock at the customer zone *l* in period *t* under joint scenario *js*

V_{jpt}	Binary variable showing the interval to which the production amount belongs
y_{jt}	Binary variable showing if capacity expansion occurs at plant j in period t
	Other notation
RC	Total raw material cost
PC	Total production cost at domestic plants
PCI	Total production cost at international plants
TC	Total transportation cost at the local plants
TCI	Total transportation cost at the international plants
TCD	Total transportation cost at the distribution centres
$TCapCj$	Total capacity expansion cost at local plants
$TCapCI$	Total capacity expansion cost at international plants
$TCapC$	Total capacity expansion costs
$TarC$	Total tariff cost
IC	Total inventory cost
ASL	Stochastic average service level to be maximized
	Parameters
$demand^{s}_{l,js}$	Possible outcome of the stochastic demand at customer zone l under joint scenario js
ξ_{js}	Joint probability of the possible outcome of the demand under joint scenario js
N_{js}	Total number of joint scenarios
C_{ijk}	The unit price of raw material i from supplier j for plant k
$\overline{Q_p}$	Upper bound for interval p of the production amount
$\overline{UPC_p}$	Production cost which corresponds to interval p of the production amount

NR_j	Total number of sub-ranges for production amount
UTC_{jkr}	Unit transportation cost from node *j* to node *k* via transportation mode *r*
LT_{jkr}	Lead-time of transportation from node *j* to node *k* via transportation mode *r*
PI	Pipeline inventory cost per period per unit of product
$Cap\ max_j$	Maximum available capacity at plant *j*
$CapC_j$	Unit capacity expansion cost at plant *j*
$Tarrif_j$	Tariff rate from international plant *j* to domestic distribution centres
UIC_j	Unit inventory cost at node *j*
LC	Lost sale penalty
OC	Overstocking penalty
E_{jt}	Exchange rate of the currency of the international plant *j*
α_i	The number of units of raw material *i* required to produce one unit of the product
β_{ij}	The amount of supplier *j*'s internal resource required to produce one unit raw material *i*
q_j	The capacity of supplier *j*
ε	Minimum required expected average service level
I	Total number of raw material types
T	Total number of planning periods
M	A big natural value

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10

Fuzzy Parameters and Their Arithmetic Operations in Supply Chain Systems

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1. Introduction

We ask the question: what is the purpose of this chapter in the whole book? This chapter is a supplement to fuzzy supply chains. The whole book could itself be divided into two parts according to the assumption whether the supply chain is a deterministic or non-deterministic system. For non-deterministic supply chains, the uncertainty is the main topic to be considered and treated. From the history of mathematics and its applications, the considered uncertainty is the randomness treated by the probability theory. There are many important and successful contributions that consider the randomness in supply chain system analysis by probability theory (Beamon, 1998; Graves & Willems, 2000; Petrovic et al., 1999; Silver & Peterson, 1985). In 1965, L.A.Zadeh recognized another kind of uncertainty: Fuzziness (Zadeh, 1965). There are several works engaged on the research of fuzzy supply chains (Fortemps, 1997; Giachetti & Young, 1997; Giannoccaro et al., 2003; Petrovic et al., 1999; Wang & Shu, 2005). While this chapter is a supplement of fuzzy supply chains, the author is of the opinion that the parameters occurring in a fuzzy supply chain should be treated as fuzzy numbers. How to estimate the fuzzy parameters and how to define the arithmetic operations on the fuzzy parameters are the key points for fuzzy supply chain analysis. Existing arithmetic operations implemented in supply chain area are not satisfactory in some situations. For example, the uncertainty degree will extend rapidly when the product $\times$ interval operation is applied. This rapid extension is not acceptable in many applications. To overcome this problem, the author of this chapter presented another set of arithmetic operations on fuzzy numbers (Alex, 2007). Since the new arithmetic operations on fuzzy numbers are different from the existing operations, the fuzzy supply chain analysis based on the new set of arithmetic operations is different from the fuzzy supply chain analysis introduced earlier. That is why the author has presented his modeling of fuzzy supply chains based on the earlier work here as a supplement to works on the fuzzy supply chains.

In Section 2, as a preliminary section, the structure and basic concepts of supply chains are described mathematically. The simple supply chains which are widely used in applications are defined clearly. Even though there have been a lot descriptions on supply chains, the author thinks that the pure mathematical description on the structure of supply chains here is a special one and specifically needed in this and subsequent sections. In Section 3, the estimation of fuzzy parameters and the arithmetic operations on fuzzy parameters are introduced. In Section 4, based on the fuzzy parameter estimations and arithmetic operations, the fuzzy supply chain analysis will be built. The core of supply chain analysis is the determination of the order-up-to levels in all sites. By means of the possibility theory (Zadeh, 1978), a couple of real thresholds the optimistic and the pessimistic order-up-to levels is generated from the fuzzy order-up-to the level of site with respect to a certain fill rate *r*. There are no mathematical formulae to calculate the order-up-to levels for all sites in general supply chains, but this is an exception whenever a simple supply chain is stationary. In Section 5, the stationary simple supply chain and the stationary strategy are introduced and the optimistic and pessimistic order-up-to the levels at all sites of a stationary simple supply chain are calculated. An example of a stationary simple supply chain is given in Section 6. Conclusions are given in Section 7.

2. The basic descriptions of supply chains

A supply chain consists of many sites (also know as stages) and each site (stage) c_i provides/produces a certain kind of part/product p_j at a certain unit/factory. For simplicity, assume that different units provide different kinds of parts/products. Let $C = \{c_1, c_2, \cdots, c_n\}$ be the set of all sites in a supply chain, and C^* be an extension of such that it includes the set of external suppliers denoted by Y and the set of end-customer centers denoted by Z :

$$C^* = Y \cup C \cup Z \tag{2.1}$$

We will simply treat an external supplier or an end-customer center also as a site. There is a relationship among the sites of C^*: If a site c_i uses materials/parts/products from a site c_j, then we say the site c_j *supplies* the site c_i and is denoted as $c_j \rightarrow c_i$. The site c_j is called an *up-site* of c_i, and c_i is called a *down-site* of c_i. The suppliers in Y have no up-sites and the customers in Z have no down-sites in C^*. The relation of supplying can be described in mathematics as a subset $S \subseteq C^* \times C^*$:

$$(c_j, c_i) \in S \text{ if and only if } c_j \rightarrow c_i. \tag{2.2}$$

If we do not consider the case of a site supplying itself, then the supplying relation *S* is anti-reflexive, i.e., for any $c_j \in C^*$, $c_j \rightarrow c_j$ is not possible. If we do not consider the case of two sites supplying each other, then *S* is anti-symmetric, i.e., for any c_i, $c_j \in C^*$, if $c_i \rightarrow c_j$, then $c_j \rightarrow c_i$ is not possible.

Definition 2.1 A *Supply chain* (C^*, S) is a set of sites C^* equipped with a supplying relation *S*, which is an anti-reflexive and anti-symmetric relation on C*.

An anti-reflexive and anti-symmetric relation *S* ensures that there is no cycle occurring in the graph of a supply chain.
Set $S^1 = S$. For any $n > 1$, set

$$S^n = \{(c_k, c_i) \mid \exists\, c_j \in C^* \text{ such that } (\mathrm{c_k}, c_j) \in S^{n-1}, (c_j, c_i) \in S\} \tag{2.3}$$

It is obvious that S^n will become an empty set when *n* is large enough. Let *h* be a number large enough such that S^h is empty. Set

$$S^* = S^1 \cup S^2 \cup \cdots \cup S^h. \tag{2.4}$$

S^* denotes the enclosure of the supplying relation on S. S^* is the relation of "supplying directly or indirectly." It is obvious that S^* is still an anti-reflexive and anti-symmetric relation. It is also obvious that S^* is a transitive relation. i.e., if $(c_k, c_j) \in S^*$ and $(c_j, c_i) \in S^*$, then $(c_k, c_i) \in S^*$.

For any site $c_j \in C$, let D_j and U_j be the set of down-sites and up-sites of c_j, respectively. Suppose that $D_j^1 = D_j$. For any $n > 1$, set

$$D_j^n = \{c_i \mid \exists\, c_{i'} \in D_j^{n-1} \text{ such that } c_{i'} \to c_i\} \tag{2.5}$$

$$U_j^n = \{c_i \mid \exists\, c_{i'} \in U_j^{n-1} \text{ such that } c_i \to c_{i'}\} \tag{2.6}$$

The sites belonging to D_j^n and U_j^n are called the *n-generation down-sites* and *up-sites* of c_j, respectively. Clearly, any down-site is the 1-generation down-site, and any up-site is the 1-generation up-site. It is obvious that D_j^n or U_j^n may become an empty set when *n* is large enough. Set

$$D_j^* = \cup\{D_j^k \mid k = 1,2,\cdots,h\} \tag{2.7}$$

$$U_j^* = \cup\{U_j^k \mid k = 1,2,\cdots,h\}. \tag{2.8}$$

These are the enclosures of D_j and U_j, and are called the *down-stream* and *up-stream* of c_j, respectively.

Proposition 2.1 For any $c_j \in C$, the downstream D_j and the upstream U_j of c_j are disjoint.

Proof Assume D_j and U_j are joint, then there is at least a site called c_i belonging to both D_j and U_j simultaneously. This leads to $c_i \leftrightarrow c_j$, which is contradicted with the requirement of the anti-symmetric of S*. Thus, the assumption is not true, and it proves that D_j and U_j are disjoint.

Proposition 2.1 just ensures that the upstream and the downstream of a site are disjoint. Unfortunately, two different generations of up-sites (or down-sites) may be intersected:

For example, let c_1 be a site supplying sugar, c_2 be a site supplying the cake mix for cakes, and c_3 be the site supplying the birthday-cakes. We have that $c_1 \to c_2$, $c_2 \to c_3$, and $c_1 \to c_3$. Since c_1 is the up-site of c_2 and c_2 is the up-site of c_3, so that c_1 is the 2-generation up-site of c_3. But c_1 is also the first generation up-site of c_3. So that $U_3^1 \cap U_3^2 \neq \phi$. Such situations may bring complexity to the research.

Definition 2.2 A supply chain (C*, S) is called a *simple supply chain* if for any site c_j in C,

$$n \neq n' \Rightarrow (D^n \cap D^{n'} = \phi \text{ and } U^n \cap U^{n'} = \phi) \tag{2.9}$$

For a simple supply chain (C^*, S), any site can be in at most one generation of upstream and at most one generation of downstream of another site.

Set

$$B = \{c \in C \mid \exists c^* \in Y \text{ such that } c^* \to c\}\text{, or} \tag{2.10}$$

$$O = \{c \in C \mid \exists c^* \in Z \text{ such that } c \to c^*\}. \tag{2.11}$$

We call a site belonging to *B* the *boundary site* and a site belonging to *O* the *root site* of *C*. For a boundary site $c_b \in B$, U_b should contain at least an external supplier: $U_b \cap Y \neq \phi$. If U_b does only contain external suppliers, i.e., $U_b \subseteq Y$, then c_b is called a *proper boundary site*. For a root site $c_0 \in O$, D_0 should contain at least a customer: $D_0 \cap Z \neq \phi$. If D_0 does only contain customers, i.e., $D_0 \subseteq Z$, then c_0 is called a *proper root site*.

We can specify some of the most important cases of simple supply chains as follows:

Case 1. **Linear supply chains**: A linear supply chain is a simple supply chain (C^*, S), C^* contains one supplier-site and one root site c_0, and each site in *C* has one 1-generation down-site and one 1-generation up-site.

It is obvious that the construction of a linear chain can be drawn as follows:

$$\text{supplier} \to c_b \to c_{h-2} \to \cdots \to c_1 \to c_0 \to \text{customer} \tag{2.12}$$

Case 2. **Anti-tree supply chains**: An anti-tree supply chain is a simple supply chain (C^*, S), C^* contains at least two supplier sites and only one root site c_0, each site in *C* has one 1-generation down-site but any number of 1-generation up-sites, and all sites are in the upstream of the only one root site c_0. An anti-tree chain represents a centralized supply chain.

It is obvious that all sites in C can be divided as different up-generations of c_0. If $c_j \in U_0^n$, we say that the *(generation) code of* c_j *for* c_0 is *n*, and denoted as $\chi_j = \chi_{j0} = n$. Since the supply chain is simple so that for any site c_j in C with code *n*, there is one and only one linear chain connecting the site c_j and c_0 given by:

$$c_j \to c_{(n-1)} \to \cdots \to c_{(1)} \to c_0 \tag{2.13}$$

Case 3. **Multiple anti-trees supply chains**: A multiple anti-trees supply chain is a simple supply chain (C^*, S), $C^* = C_1^* \cup C_2^* \cup \cdots \cup C_m^*$, and for $1 \le k \le m, (C_k^*, S_k)$ are anti-tree supply chains, where $S_k = S \cap (C_k^* \times C_k^*)$, the constraint of *S* on C_k^*. Each root site $c_{0(k)}$ is a proper root site. A multiple anti-trees chain represents a decentralized supply chain.

Omitting the proof, we can say that a multiple anti-trees supply chain is a combination of several anti-tree supply chains. It is obvious that there are several supplier-sites and many proper root sites. Each site in C has no limit on the number of 1-generation down-sites and 1-generation up-sites, but each site should be in the upstream of at least one proper root site. It is obvious each site c_j in C has a code χ_{j0} for a root-site c_0 if $c_j \to c_0$, and has one and only one linear chain connecting c_j and c_0 .Case 2 is a generalization of case 1, and the case 3 is a generalization of case 2. In the rest of the chapter, we will limit our attention to case 2 of a simple supply chain.

For each site c_j in C, let $q_{ji}(t)$ be the order quantity of p_j -part/material from the down-site c_i, which is called the *order-away quantity* of c_j at time *t*. While $q_{kj}(t)$, the p_k-part/material quantity in up-site c_k ordered by c_j, is called the *order-in quantity* of c_j at time *t*.

The following *review period policy* is assumed here: For any site c_j in C, the time of ordering in the up-parts could not be arbitrary, but limited at t_j, $t_j + T_j$, $t_j + 2T_j, \cdots$. These timings are called the r*eview times*, and $T_j > 0$ is called the *review period* of c_j. To be simple, assume that $t_j = 0$ for any c_j in C.

For any site $c_j \in C$, suppose that $c_j \to c_i$. Set

$$\alpha_j(nT_j) = \sum \{q_{ji}(t) \mid \exists i \in C; (n-1)T_j \le t < nT_j\}, \tag{2.14}$$

is the number of p_j-parts that has been ordered to be sent out to the down-site of c_j during the last period $(n-1)T_j \le t < nT_j$ and is called the *passed away number* of p_j's in the last period. Set

$$\overline{\alpha}_j(nT_j) = (\frac{1}{T_j})(\alpha_j(nT_j)). \tag{2.15}$$

This is called the *order-away rate* of p_j at the time t. For a root-site c_0, the passed-away number of p_0–products is called the *demand number* at time *t* denoted as $d(nT_0) = \alpha_0(nT_0)$. Set

$$\overline{d}(t) = (1/T_0)(d(t)). \tag{2.16}$$

This is called the *demand rate* of p_0 at the time *t*.

Suppose that each p_i-product/part is produced by means of w_{ji} pieces of p_j-parts, we call w_{ji} the *equivalence* of a p_i-part for the p_j-part. For any site pair $(c_j, c_i) \in S$, there is an equivalence value w_{ji}, which reflects the production ingredient of down-products by means of the up-parts.

In case 2, for any site c_j in C with code $\chi_j = n$, there is one and only one linear chain connecting it to its root site c_0 as: $c_j \to c_{(n-1)} \to \cdots \to c_{(1)} \to c_0$. Set

$$w_j = w_{(j)(n-1)} w_{(n-1)(n-2)} \cdots w_{(1)(0)}. \tag{2.17}$$

This is called the *equivalence* of a product for the p_j-part. The production of each final product p_0 needs w_j pieces of p_j-parts to supply it.

The main problem in supply chain analysis is: How to set up the reasonable inventory levels in all sites of C? Let $I_j = I_j(t)$ be the real inventory of p_j-parts of site c_j at time $t = nT_j$. This should be a negative number whenever it is in shortage at the time. We do not want a site to be in the shortage, so we want that I_j >0; While its value should not be too high since then there will be a high inventory maintenance cost; The goal of supply chain management is to minimize the supply chain inventory cost and to limit the possibility of shortage as much as possible.

The expected inventory level of the site c_j at the time $t = nT_j$ should be responsible not only for supplying the down-site of c_j during the next period $[nT_j, (n+1)T_j]$, but also for a longer time until the birth of the next batch of p_j-parts produced from up-parts ordered in c_j at the next review time $t' = (n+1)T_j$. The length from $t = nT_j$ to the mentioned time can be denoted as

$$T_j^* = T_j + L_j. \tag{2.18}$$

This is called the *looking time* of c_j; while L_j is called the *replenishment time* of c_j. The concrete expression of L_j is

$$L_j = M_j + G_j + P_j, \tag{2.19}$$

where

$$M_j = \max\{M_{kj} \mid k \in U_j\};$$

$$G_j = \max\{G_{kj} \mid c_k \in U_j\};$$

$$P_j = (\alpha_j(nT_j) \times T_j \times \tau_j \times (1 + \varphi_j \times \vartheta_j)) / C_j. \tag{2.20}$$

M_{kj} is the time of transferring the ordered p_k-parts from the site c_k to the site c_j at a review time $t = nT_j$, called the *material lead time* from c_k to c_j; G_{kj} is the time of delaying of the transferring of the ordered p_k-parts owing to the shortage of p_k-parts, called the *delay time* of p_k-parts for c_j; P_j is the time of transferring the p_k-parts into p_j-parts at the site c_j, called the *production time* of c_j, with the following parameters: τ_j the cycle time for p_j; φ_j the estimated number of occurrences of downtime; ϑ_j, the duration of downtime on the production line for c_j; C_j the production capacity, the working hours per day, allocated for c_j. Set

$$S_j = \alpha_j(nT_j) \times (T_j + L_j), \tag{2.21}$$

which stands for the reasonable inventory level of site c_j at time $t = nT_j$. S_j is called the order-up-to level of site c_j at time $t = nT_j$.

$$S_{kj}^* = w_{kj} \times (S_j - I_j), \tag{2.22}$$

which is the real order of p_k-parts from site c_j at time $t = nT_j$.

The main task in supply chain analysis is the determination of the order-up-to levels $\{S_j\}_{(j=1,\ldots,n)}$ in all sites of the chain at a time *t*.

3. Fuzzy parameters and their estimation and arithmetic operations

Since this chapter is a supplement of fuzzy supply chain analysis, we avoid repeating the statements on what is fuzziness, what is the different between fuzziness and randomness, and so on. But it should be emphasized here again that fuzzy theory is good at imitating the subjective experience of human beings.

When we face an unknown parameter with fuzziness in a supply chain, the natural way is representing it by a fuzzy number. There are two key points: First, how to estimate the parameters? i.e., how to get a fuzzy number to represent the estimation by experts for a parameter? Second, how to make reasonable arithmetic operations on the fuzzy parameters?

3.1 How to estimate a fuzzy parameter?

The fuzzy estimation reflects the subjective measurement about a real number by an expert (or a group of experts) who has knowledge and experience with respect to the estimated parameter. The process of subjective estimation has no general rules as guide; every case has its own approach. An expert pointing out the location of an expected number depends on his inference, which is based on the experience of grasping the main essential factors in the practical situation. Under some factor-configuration, the expert will make a choice. But when the factor-configuration has been changed, the expert will have another choice. To acquire an expert's estimation into a fuzzy number, we could learn from psychological statistics. There are many methods that could be adopted. To be simple, the author shortens some of the methods and suggests by asking an expert the following questions:

Question 1: What is the real number in your mind, which is the most acceptable for you to represent a fuzzy parameter α ?

Let a real number a be the answer, then we say that the fuzzy parameter α has the *estimation value* a , denoted as $a = m(\alpha)$.

Question 2: What is the confidence on your estimation for α ? Please place the mark × on a proper location in the real number line that represents the confidence interval [0, 1]. The expert points out a mark × at the proper position in the interval [0, 1] to represent the degree of his confidence on the estimation of the number in question 1. For example, according to the location of the mark shown in the Fig. 1, we can get a real number φ =0.75, which is called as the *confidence degree* of the expert on his estimation.

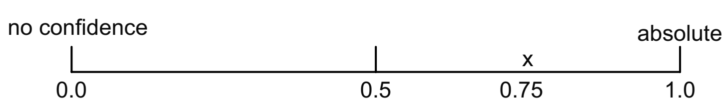

Figure 1. The confidence on the parameter estimation

If the confidence degree equals 1, then the expert must make sure that the estimation value *a* is true absolutely and there is no error in the estimation. If the confidence equals to 0, then the expert knows nothing about this estimation.

Suppose that there is a group of experts that make estimations of fuzzy parameters within a supply chain system. Each expert has a score $\rho \in [0,1]$ to represent his skill degree on subjective estimation. The closer the score value is to 1 the higher the authority. The score can be measured and adjusted by the success rate in practical situations. ρ is called the *authority index* of the expert. The product of the authority index ρ of an expert and the confidence degree φ of his estimation on a fuzzy parameter represents the subjective accuracy of this estimation, denoted as $\tau = \rho \times \varphi$. We call $\delta = 1 - \tau$ the *ambiguity degree* of the estimation. A fuzzy parameter α can be represented by a pair of two real numbers, its estimation value a and its ambiguity degree δ:

$$\alpha = a(1 \pm \delta),\ (0 \le \delta \le 1). \tag{3.1}$$

The ambiguity degree of the parameter α could also be called the *estimation error* of the estimation in α, and denoted as $\delta = e(\alpha)$. The formula (3.1) looks like the representation of error in measurement theory. Yes, they are very similar. The only difference is: The error in measurement is caused by the impreciseness of instruments and observation; while the ambiguity is caused by the fuzziness in subjective estimation. In the error theory, there are two kinds of errors: absolute error and relative error. The ambiguity reflects the error in subjective estimation and it is not an absolute error, but a relative error. The relative error plays a more essential role. For examples, when we estimate that the height of the wall as 2 ± 0.2 units, the estimation value is $a = 2$ units and the absolute error is $a \times \delta = 0.2$; when we estimate that the length of the street is 2000 ± 200 units, the estimation value is $a = 2000$ units and the absolute error is $a \times \delta = 200$; when we estimate that the length of an insect is 0.002 ± 0.0002 units, the estimation value is $a = 0.002$ and the absolute error is $a \times \delta = 0.0002$.There are differences in the three examples, but the relative error is the same $\delta = 0.1$. The estimation errors are invariable on the changing of unit. It reflects the intrinsic quality of subjective estimation.

We represent the membership function of a fuzzy parameter estimation by a triangle fuzzy number taking its peak at the estimation value *a* and its radius as $r = |a| \times \delta$:

$$\mu_\alpha(x) = \begin{cases} 0 & if\ -\infty < x \le a - r \\ 1 + \dfrac{x-a}{r} & if\ a - r < x \le a \\ 1 - \dfrac{x-a}{r} & if\ a < x \le a + r \\ 0 & if\ a + r < x < \infty \end{cases} \tag{3.2}$$

Since $0 \le \delta \le 1$, a fuzzy parameter is a special triangle fuzzy number whose radius is $r \le |a|$.

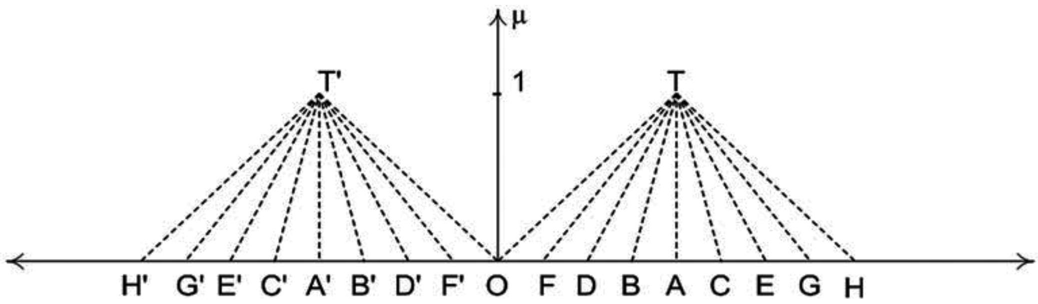

Figure 2. Example of 10 fuzzy parameters

In the Fig. 2, we can see a set of fuzzy parameters with estimation value $a = 100$ have membership functions shown as the broken lines $ATA, BTC, DTE, FTG, \text{and } OTH$ with ambiguity $\delta = 0, 0.25, 0.5, 0.75, \text{and } 1$, respectively; those fuzzy parameters with estimation value $a' = -100$ have membership functions shown as the broken lines $A'T'A'$, $B'T'C'$, $D'T'E'$, $F'T'G'$, and $O'T'H'$ with ambiguity $\delta = 0, 0.25, 0.5, 0.75, \text{and } 1$, respectively.

Definition 3.1 Given a positive real number 0≤δ*≤1, we call *V*, the set of fuzzy parameters $\alpha = a \pm r$ with $\frac{r}{|a|} \le \delta *$, the $\delta *$-*systems* of fuzzy parameters.

For example, suppose that *V* is a 0.05-system of fuzzy parameters. The fuzzy parameter $2 \pm 1 \notin V$ since $\frac{r}{|a|} = 0.5 > 0.05$. The fuzzy parameter $1 \pm 0.05 \in V$ since $\frac{r}{|a|} = 0.05$.

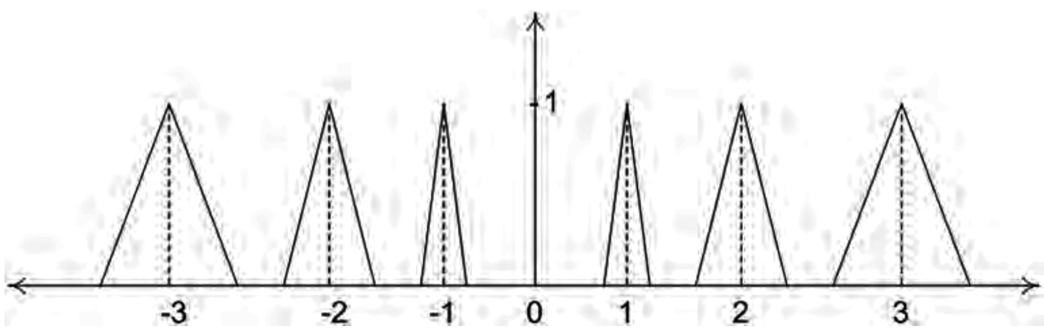

Figure 3. The δ*-system of fuzzy parameters

In the Fig. 3, the radius of the fuzzy parameter $-3 \pm 3\delta *$ is $3\delta *$, the radius of the fuzzy parameter $-2 \pm 2\delta *$ is $2\delta *$, and the radius of the fuzzy parameter $-1 \pm \delta *$ is $\delta *$. The radius of fuzzy parameter $1 \pm \delta *$ is $\delta *$; the radius of fuzzy parameter $2 \pm 2\delta *$ is $2\delta *$; and the radius of fuzzy parameter $3 \pm 3\delta *$ is $3\delta *$. As we see from figure 3, the estimation values closer to zero, the narrower the membership function width; the estimation value farther away from zero, the wider the membership function width. However, the ambiguities of the fuzzy parameters in a δ^*-system are all restricted by δ*. A δ^*-system includes not only those fuzzy parameters whose ambiguities are equal to δ^*, but all fuzzy parameters whose ambiguities are less than δ^*. The δ^*-systems are not disjoint but expanded when the parameter δ^* is increasing: $\delta_1{}^*-$system $V_1 \subseteq \delta_2{}^*-$system V_2 $(\delta_1 \leq \delta_2)$.

Proposition 3.1 Suppose that V is a δ^*-system of fuzzy parameters, where $0 \leq \delta^* \leq 1$. For any non-zero fuzzy parameter $\alpha = a \pm r \in V$, the support of α does not contain zero as an inner point. i.e., $0 \notin (a-r, a+r)$.

Proof Assume that $0 \in (a-r, a+r)$. If $a > 0$, then $1-\frac{r}{a} < 0 < 1+\frac{r}{a}$. Then $1-\delta^* \leq 1-\frac{r}{a} < 0$, i.e., $\delta^* > 1$. This is a contradiction to the requirement of $\delta^* \leq 1$. Suppose that $a < 0$, then $1-\frac{r}{a} > 0 > 1+\frac{r}{a}$. Since $\delta^* \geq |\frac{r}{a}| = -\frac{r}{a}$, $0 > 1+\frac{r}{a} \geq 1-\delta^*$, i.e., $\delta^* > 1$. This is a contradiction with the requirement of $\delta^* \leq 1$. According to the reduction to absurdity, the assumption is not true. So $0 \notin (a-r, a+r)$.

Using Proposition 3.1, we can say that a fuzzy parameter α is positive if the estimation value of α is positive, and α is negative if the estimation value of α is negative. Proposition 3.1 constrains the fuzzy parameters in our $\delta-$system in pure sign, i.e., the support of any fuzzy parameter does not contain zero. This is not a real constraint in practical but reflects such a faith in the thinking process: Human beings like to do fuzzy estimation on "how much" but not fuzzy on the main direction to do it. For example, suppose we are telling somebody: "To go to the post office, turn left and go about 150 meters". It may be acceptable if the distance is not estimated precisely; the distance is not exactly 150 meters, instead it is 164 meters. But it is not acceptable if the direction to turn left is wrong. A $\delta-$system is free in use if we put the zero point in such a place from where the directions toward West and East are distinguished.

It is worth noting that the ambiguity δ of a fuzzy parameter α could be larger than zero whenever its estimation value $a = 0$. In this case, $\alpha = a \pm |0| \times \delta = a \pm 0$. Indeed, for a fuzzy parameter with estimation value zero, it can have arbitrary ambiguity δ.

However, we can make an assumption that for a fuzzy parameter with zero estimation value, we rewrite its ambiguity as zero no matter how large its ambiguity is.

The fuzzy parameters we defined here indeed are triangle fuzzy numbers with a little constraint. The reason for making a different name for them is not to emphasize the constraint, but to emphasize the different definitions of arithmetic operations on them.

3.2 Arithmetic operations of fuzzy parameters

The existing arithmetic operations of fuzzy numbers are based on the extension principle of set mappings and in accordance with the operations of interval numbers are:

$$[a,b]+[c,d]=[a+c,b+d] \tag{1}$$

$$[a,b]-[c,d]=[a-d,b-c] \tag{2}$$

$$[a,b]\times[c,d]=[\min\{ac,ad,bc,bd\},\max\{ac,ad,bc,bd\}] \tag{3}$$

$$\frac{[a,b]}{[c,d]}=[\min\{\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d}\},\max\{\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d}\}] \tag{4}$$

The operation product $\times$ in equations (3) has the problem that the range of the interval may increase rapidly. For example, consider two interval numbers $I=[-2,3]$ and $I'=[100,200]$. According to equation (3) the product of I and I' is $I\times I'=[-400,600]$. The range of interval I is 5, the range of interval I' is 100. But the range of the interval $I\times I'$ is 1000. This rapid expansion of the range of the interval $I\times I'$ is not acceptable. The radius of fuzzy numbers will extend rapidly when performing the operations of product and division.

In the search for new fuzzy arithmetic calculus where the uncertainty involved in the evaluation of the underlying operation does not increase excessively, there has been some works done in fuzzy set theory. D.Dubois and H. Prade (Dubois & Prade, 1978; Dubois & Prade, 1988) have employed the t-norm to extend the operation of membership degrees for defining the Cartesian product of fuzzy subsets and then generalized Zadeh's extension principle to t-extension principle. Their work has made an order among different t-norms using an inequality according to its effectiveness of restraining the increasing of uncertainty involved in the evaluations across calculations. The more the t-norm is to the left of the inequality the better the arithmetic operation. The minimum t-norm T_m, which corresponds to the existing operations related to equations (1) through (4), sits on the right-extreme end of the inequality. People then look toward the left of the inequality to search for a t-norm to get more reasonable fuzzy calculations along the t-norm ordering. This is a direction guiding our research. Especially, people focus attention on the t-norm T_w, which sits on the left-extreme end of the t-norm ordering inequality. Many worthy works have been published recently along this direction (Hong, 2001; Mares & Mesiar, 2002) Mula et al., 2006).

The extension principle is a prudent principle in mathematics to define set-operations. It considers all possible; no omission! That is why it causes the extension rapidly. Based on the extension principle, any definition of the operation $\times$ for fuzzy numbers could not avoid the decreasing of uncertainty, even using the t-norm T_w. The operations of random variables are indeed defined according to a kind of extension principle, which can carry probabilities. Existing arithmetic operations for fuzzy numbers and the operations for random variables are all constructed in an objective approach. However, experts' estimation is a subjective approach. It is a decisive principle: Don't care about omissions, but do aim at the essential point; neglect the unimportant points even though they are possible to occur; only concentrate on the most important location. The width (radius) of the membership function of a fuzzy parameter does not reflect on any relevant objective distribution, but only the subjective accuracy. The arithmetic operations of fuzzy parameters keep the operations on the estimated values of the fuzzy parameters. As ordinary real numbers, they keep ordinary arithmetic operations. The additional consideration here is the operations of their estimation errors. When two fuzzy parameters α_1 and α_2 have the same estimation error δ, then the same estimation error δ is applied to $\alpha_1 \pm \alpha_2$ or $\alpha_1 \times \alpha_2$, or $\alpha_1 \div \alpha_2$; If they have different estimation errors, then the estimation error of $\alpha_1 \pm \alpha_2$ or $\alpha_1 \times \alpha_2$, or $\alpha_1 \div \alpha_2$ must be between the two original estimation errors. Hence the following definition:

Definition 3.2 Let $\alpha_i = a_i \pm |a_i| \times \delta_i$, $(i = 1, 2)$. The arithmetic operations of fuzzy parameters are defined as:

$$m(\alpha_1 + \alpha_2) = a_1 + a_2,\ e(\alpha_1 + \alpha_2) = \delta_1 * \delta_2; \tag{3.3}$$

$$m(\alpha_1 - \alpha_2) = a_1 - a_2,\ e(\alpha_1 - \alpha_2) = \delta_1 * \delta_2; \tag{3.4}$$

$$m(\alpha_1 \times \alpha_2) = a_1 \times a_2,\ e(\alpha_1 \times \alpha_2) = \delta_1 * \delta_2; \tag{3.5}$$

$$m(\alpha_1 \div \alpha_2) = a_1 \div a_2,\ e(\alpha_1 \div \alpha_2) = \delta_1 * \delta_2. \tag{3.6}$$

Here

$$\min\{\delta_1, \delta_2\} \le \delta_1 * \delta_2 \le \max\{\delta_1, \delta_2\}. \tag{3.7}$$

For simplicity, we define $\delta_1 * \delta_2 = \max\{\delta_1, \delta_2\}$ in this work. The inequalities in (3.7) could be called the *estimation-error-limitation principle*. This effectively prevents the rapid extension of uncertainty when the arithmetic operations of fuzzy parameters are taken into consideration.

It is not difficult to see that the new arithmetic operation definitions on fuzzy parameters and the ordinary arithmetic operation definitions of fuzzy numbers are coincident for the operations + and – whenever $\delta_1 = \delta_2$. Of course, they are not coincident on the × and ÷ operations.

4. The application of the new arithmetic operations in supply chains

We observe that the value of $q_{ji}(t)$, the order-away quantity of c_j at time *t*, is not known yet. If it is not deterministic, then uncertainties occur when we take estimation on this value.

As mentioned earlier, there are two kinds of uncertainties: randomness and fuzziness. If there are enough data representing the past values and the conditions related to those data are continuing onto the present, then the value $q_{ji}(t)$ could be treated as a random variable; otherwise, if there is not enough statistical data available, or if the conditions have been changed, it could be better treated as a fuzzy parameter and be estimated as mentioned in Section 3. As a supplement to the existing treatments of uncertainty in supply chain analysis, this chapter presents a new phase of the uncertainties treatment when we encounter randomness and fuzziness simultaneously. Accordingly, no matter whether the parameter is a random variable or a fuzzy number, it is always treated as a fuzzy parameter:

$$q_{ji}(t) = m(q_{ji}(t))(1 \pm \delta(q_{ji}(t)));$$

$$m(q_{ji}(t)) = E(q_{ji}(t)), \delta(q_{ji}(t)) = \sigma(q_{ji}(t)) \text{whenever} q_{ji}(t) \text{is a random variable} \quad (4.1)$$

Here $E(q_{ji}(t))$ is the mathematical expectation of $q_{ji}(t)$ and $\sigma(q_{ji}(t))$ is the root-mean-square error of $q_{ji}(t)$. Why does the author treat a random variable as a fuzzy parameter? Because the core modeling for fuzzy supply chain analysis is imitating the experts' experiences. Experts responsible for fuzzy supply chain analysis apply their skill at two stages: 1. Estimating value of each involved parameter; 2. Choosing of arithmetic operations on fuzzy parameters according to the estimation-error-limitation principle. In the first stage, if the estimated value is the mathematical expectation of a random variable, then the expert could rely on the objective methods in probability theory and get the resulting value. That is fine! It could save expert's time to do subjective estimation. Whenever the fuzzy estimations have been input into the second stage, the root-mean-square error has been transferred into the estimation error in the fuzzy parameters' operations. This will not involve operations on the probability distributions of random variable. Apart from taking the operations $\pm$ on independent variable, there may not be any need to do rigid probabilistic operations on random variables' in the practical applications.

Similarly, the *order-away quantity* of c_j at time *t*, $a_j(t)$, is also a fuzzy parameter no matter it is a random variable or a fuzzy number.

$$\alpha_j(t) = m(\alpha_j(t))(1 \pm e(\alpha_j(t))). \quad (4.2)$$

Here

$$m(\alpha_j(t)) = \sum \{m(q_{ji}(t')) \mid \exists i \in C, t \le t' < t + T\} \quad (4.3)$$

$$e(a_j(t)) = \max\{\langle e(\alpha_j(t')) \big| \exists i \in C \;\; and \; t \le t' \le t + T\} \quad (4.4)$$

The *order-away rate* of p_j at the time t, $\overline{\alpha}_j(t)$, is also a fuzzy parameter no matter it is a random variable or a fuzzy number.

$$\overline{\alpha}_j(t) = m(\overline{\alpha}_j(t))(1 \pm e(\overline{\alpha}_j(t))),\tag{4.5}$$

where

$$m(\overline{\alpha}_j(t) = \frac{1}{T_j}(m(\alpha_j(t))),\tag{4.6}$$

$$e(\overline{\alpha}_j(t) = e(\alpha_j(t)).\tag{4.7}$$

For a root-site c_0, the demand number at time *t* is treated as a fuzzy parameter $d(t) = m(d(t))(1 \pm e(d(t)))$. The demand rate of p_0 at the time *t*, treated as a fuzzy parameter

$$\overline{d}(t) = m(\overline{d}(t))(1 \pm e(\overline{d}(t))).\tag{4.8}$$

The material lead time from c_k to c_j, M_{kj}, is also to treated as a fuzzy parameter no matter it is a random variable or a fuzzy number.

$$M_{kj} = m(M_{kj})(1 \pm e(M_{kj}))$$

$$m(M_{kj}(t)) = E(M_{kj}(t)), e(M_{kj}(t)) = \sigma(M_{kj}(t)) \text{whenever} M_{kj}(t) \text{ is a random variable}\tag{4.9}$$

$$M_j = m(M_j)(1 \pm e(M_j));\tag{4.10}$$

Here

$$m(M_j) = \max\{m(M_{kj}) \mid k \in U_j\}\tag{4.11}$$

$$e(M_j) = \max\{e(M_{kj}) \mid k \in U_j\}\tag{4.12}$$

The delay time of p_k -parts for c_j, G_{kj}, is also to be treated as a fuzzy parameter:

$$G_{kj} = c(G_{kj})(1 \pm \delta(G_{kj}));$$

$$m(D_{kj}(t)) = E(G_{kj}(t)), e(G_{kj}(t)) = \sigma(G_{kj}(t)) \text{whenever } G_{kj}(t) \text{is a random variable}\tag{4.13}$$

$$G_j = m(G_j)(1 \pm e(G_j))\tag{4.14}$$

Where

$$m(G_j) = \max\{m(G_{kj}) \mid k \in U_j\}\tag{4.15}$$

$$e(G_j) = \max\{e(G_{kj}) \mid k \in U_j\}\tag{4.16}$$

Although it is possible along the same line as above, we omit writing the fuzzy parameters such as the deterministic quantities: the cycle time τ_j, the estimated number of occurrences of downtime φ_j, the duration of downtime on the production line ϑ_j. While the production capacity C_j is a deterministic number, it could be also treated as a fuzzy parameter provided we take $m(C_j) = C_j$ and $e(C_j) = 0$. The replenishment time of c_j, L_j, is also treated as a fuzzy parameter

$$L_j = m(L_j)(1 \pm e(L_j)), \tag{4.17}$$

where

$$m(L_j) = m(M_j) + m(G_j) + P_j. \tag{4.18}$$

The order-up-to level for site c_j at time *t*, $S_j(t)$ is a fuzzy parameter, which is the product of $\alpha_j(nT_j)$ and $(T_j + L_j)$ is:

$$S_j(t) = \alpha_j(nT_j) \times (T_j + L_j) = m(S_j(t))(1 \pm e(S_j(t))), \tag{4.19}$$

where

$$m(S_j(t)) = m(\alpha_j(nT_j)) \times (T_j + m(L_j)),$$

$$e(S_j(t)) = \max\{e(\alpha_j(nT_j)), e(L_j))\}. \tag{4.20}$$

We note that shortage may occur whenever

$$I_j(t) < S_j(nT_j), \tag{4.21}$$

where $nT_j \le t < nT_j + L_j(t)$. It implies that the shortage interval could be roughly written as $(-\infty, S_j)$. But since S_j is a fuzzy number, the interval is not a crisp interval. To conveniently control the inventory, we need to pick out two thresholds from S_j: two real numbers S_j^o and S_j^p called the *optimistic* and the *pessimistic* order-up-to levels of site c_j, respectively. They are determined by the following equations:

$$\Pi^+(S_j^o) = r = N(S_j^p), \tag{4.22}$$

where r is a given fill rate, A typical value is $r = 0.95$; and

$$\Pi^+(x) = \max\{\mu_{S_j}(u) \mid u \le x\},\ N(x) = 1 - \max\{\mu_{S_j}(u) \mid x > u\}. \tag{4.23}$$

These are called the left possibility function and the necessary function of fuzzy variable S_j respectively. We have a formula to get the two real order-up-to levels from the fuzzy order-up-to level:

4.1 Proposition

$$S_j^o = (1 - e(S_j) + r \times e(S_j)) \times m(S_j);$$

$$S_j^p = (1 + r \times e(S_j)) \times m(S_j). \tag{4.24}$$

Proof The increasing part of the left possibility function is in accordance with the left-wing of the membership function of the fuzzy parameter S_j. It is obvious that

$$\Pi^+(S_j^o) = \mu_{S_j}(S_j^o) = (S_j^o - m(S_j) + e(S_j) \times m(S_j))/(m(S_j) \times e(S_j)).$$

From (4.22) we get

$$(S_j^o - m(S_j) + e(S_j) \times m(S_j))/m(S_j) \times e(S_j) = r$$

$$S_j^o = r \times m(S_j) \times e(S_j) + m(S_j) - e(S_j) \times m(S_j) = (1 - e(S_j) + r \times e(S_j)) \times m(S_j)$$

.

This is the optimistic threshold. Similarly, we can get the pessimistic threshold.

A key task of fuzzy supply chain analysis is the determination of the optimistic and the pessimistic order-up-to levels of all sites in the supply chain.

5. Stationary strategy

The roles of a supply chain are transferring raw materials as parts-flow, flowing down along the supply chain network, and the quantities of the flow are determined by information-flow flowing up inversely. There are no mathematical formulae to calculate the order-up-to levels for all sites in general supply chains. However, there could be the possibility for special simple supply chains, which are stationary supply chains defined as follows:

Definition 5.1 Suppose that (C, S) is a simple supply chain. When $\bar{d}(t) \equiv \bar{d}(a \le t \le b)$ where $\bar{d}$ is a fuzzy parameter, we say that the simple supply chain is *stationary* on the interval $[a, b]$.

Just as the stationary random process has a stationary distribution, a stationary supply chain has a stationary possibility distribution with a constant demand rate $\bar{d}$. Of course, the real demand from the customers is still a variable. No mater how complex the supply chain system is, we can think of it as a network of water flow. In the water flow network, we will have a stationary flow whenever the input equals the output at every node. To maintain a stationary flow in a supply chain network, the best way is for any site to know how many units passed away during the last period; how many units should be ordered back in the review time. Here comes the stationary strategy.

Stationary Strategy: For a simple supply chain with any site $c_j \in C$, and any $n > 0$, the number of passed away quantity $\alpha_j(nT_j)$ of c_j is known at the time $t = nT_j$, without special note, the default order-in quantities of c_j may be given by the following formula:

$$q_{kj}(nT_j) = w_{kj} \times \alpha_j(nT_j) \quad (k \in U_j)\,. \tag{5.1}$$

Stationary strategy aims to lead the parts-flow within the supply chain network achieving the equilibrium between output and input at every site. Even though the equilibrium is not synchronous but with a time-delay, the supply chain network will keep constant inventory for each site after a while.

Proposition 5.1 Suppose that a simple supply chain is stationary: $\overline{d}(t) \equiv \overline{d}$. Under the stationary strategy, the passed-away number for each site c_j in C is also stationary which is given by:

$$\alpha_j(nT_j) \equiv \alpha_j = w_j \times \overline{d} \quad (n = 1,2,...)\,. \tag{5.2}$$

Proof. We use the principle of mathematical induction for the code $n = \chi(c_j)$.

Assume that the Proposition is true for any c_j with code $n = \chi(c_j) = 1$. Indeed, $\chi(c_j) = 1$ implies that $c_j \to c_0$. It is obvious that (5.2) is true for the base case.

Suppose that (5.2) is true for *n*, we are going to prove that it is true for $n+1$. Suppose that $c_j \to c_i$ and $\chi(c_j) = n$, then $\alpha_j(t) = w_i \times \overline{d}$. We have that

$$\alpha_j(mT_j) = w_{ji} \times \alpha_i(mT_i) = w_{ji} \times w_i \times \overline{d} = w_j \times \overline{d}$$

So (5.2) is true.
According to (4.20), we have

$$m(S_j(t)) = w_j \times m(\overline{d}) \times (T_j + m(L_j))$$

$$e(S_j(t)) = \max\{e(\overline{d}), e(L_j)\} \tag{5.3}$$

Since the chain is in stationary, we can write $m(L_j)$ in detail according to (4.1)-(4.18) and get

$$m(S_j) = w_j \times m(\overline{d})$$

$$\times (T_j + \max\{c(M_{kj}) \mid k \in U_j\} + (m(\overline{d}) \times w_j \times T_j \times c(\tau_j) \times (1 + c(\varphi_j) \times c(\vartheta_j))) / C_j)$$

$$e(S_j) = \max\{\max\{e(M_{kj}) \mid k \in U_j\},\, e(\overline{d}),\, e(\tau_j),\, e(\varphi_j),\, e(\vartheta_j)\}\,. \tag{5.4}$$

According to (4.24), we get

$$S_j^o = (1 - e(S_j) + r \times e(S_j)) \times w_j \times m(\overline{d}) \times (T_j + \max\{...\} + ...)$$

$$S_j^p = (1 + r \times e(S_j)) \times w_j \times m(\overline{d}) \times (T_j + \max\{...\} + ...) \tag{5.5}$$

The likely situations of a simple supply chain system are that: 1. Supply chain is stationary; 2. the inventory in each site is keeping its order-up-to level. In this situation, the simple chain is in the optimal situation and the parts flow is stationary with the minimum inventory cost and fulfills the target fill rate on the final products at the root.

Definition 5.2: A simple supply chain is called *optimal* if it is in the stationary situation and the inventory number equals to the order-up-to level in all the sites of the chain.

When a simple supply chain is stationary but the inventory number is not equal to the order-up-to level in each site, then we can take the following strategy to push the supply chain to attain an optimal situation:

Optimal strategy: For a simple stationary supply chain at the review time $t = nT_j$ on the site c_j,

1. If $I_j(t) \le S_j^o + w_k \times m(\overline{d}) \times T_j$, then take $q_{kj} = w_k \times m(\overline{d}) \times T_j + (S_j^o - I_j(t))$
2. If $I_j(t) > S_j^p + w_k \times \overline{d} \times T_j$, then take $q_{kj} = 0$. (5.6)

Here $I_j(t)$ is the inventory of c_j at review time *t*. We can see that the optimal strategy (5.6) is the same as the stationary strategy (5.1) whenever $I_j(t) = S_j$. It means that whenever the inventory equals the order-up-to level, the optimal strategy automatically returns to the stationary strategy to keep the inventory at the order-up-to level successively. The optimal situation could be conserved until the demand rate $\overline{d}$ is changed.

6. Example

To apply the theory described above to a problem, an example (Wang and Shu, 2005) is adapted in this section. Assume that a supply chain contains one distribution center, the root-site c_0 and six production facilities: c_0 has one up-site c_1; c_1 has three up-sites c_2, c_3, and c_4; c_2 has an up-site c_5; and c_5 has one up-site c_6. The site c_1 has also two external suppliers s_1 and s_2. The sites c_3, c_4 and c_6 are proper boundary sites: four external suppliers s_4, s_5, s_6, and s_7, supply the site c_3, s_3 supplies the site c_6, and s_8 supplies the site c_4. So that the supply chain for the problem consists of $C = \{c_0, c_1, c_2, c_3, c_4, c_5, c_6\}$ and $C^* = C \cup \{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8\}$. The graphical representation of the supply chain is shown in Fig. 5.

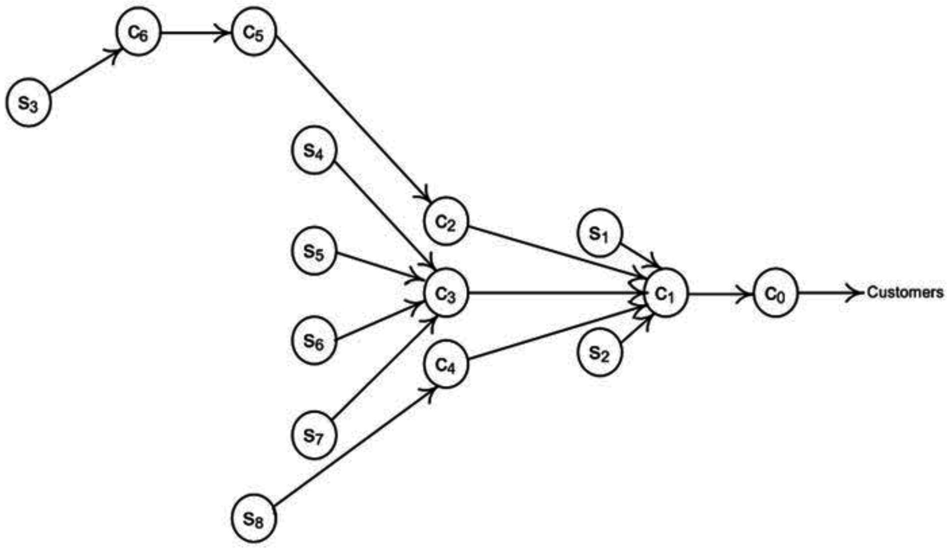

Figure 5. Example of a simple supply chain network

Assume that the *equivalence* of a product for p_j -parts is $w_j = 1$, $(j = 1, 2, \cdots, 6)$. The supply chain is simple and is assumed stationary and the daily customer demand for the finished product at the root-site c_0 is the fuzzy number $\overline{d} = 200(1 \pm 0.5)$.

Assume that the review periods (days) are given as: $T_0 = 2$, $T_1 = 3$, $T_2 = 4$, $T_3 = 3$, $T_4 = 3$, $T_5 = 4$, $T_6 = 5$. Let the production cycle times (10^{-2} times/hr) be given as the following with estimations:

$m(\tau_1) = 4.2$, $m(\tau_2) = 2.0$, $m(\tau_3) = 3.0$, $m(\tau_4) = 3.3$, $m(\tau_5) = 3.2$, $m(\tau_6) = 2.8$

and degree of ambiguities:

$e(\tau_1) = 0.3$, $e(\tau_2) = 0.25$, $e(\tau_3) = 0.3$, $e(\tau_4) = 0.2$, $e(\tau_5) = 0.1$, $e(\tau_6) = 0.3$.

Let the downtime frequencies (10^{-3} times/hr) be given as the following with estimations:

$m(\varphi_1) = 1.3$, $m(\varphi_2) = 1.4$, $m(\varphi_3) = 1.3$, $m(\varphi_4) = 1.5$, $m(\varphi_5) = 1.7$, $m(\varphi_6) = 1.5$

and degree of ambiguities:

$e(\vartheta_1) = 0.15$, $e(\vartheta_2) = 0.14$, $e(\vartheta_3) = 0.12$, $e(\vartheta_4) = 0.2$, $e(\vartheta_5) = 0.13$, $e(\tau_6) = 0.12$.

Let the downtime (hr/time) be given as the following with estimations:

$m(\vartheta_1) = 2.0$, $m(\vartheta_2) = 2.2$, $m(\vartheta_3) = 2.3$, $m(\vartheta_4) = 1.9$, $m(\vartheta_5) = 3.0$, $m(\vartheta_6) = 2.5$, and the degree of ambiguities

$e(\vartheta_1) = 0.15$, $e(\vartheta_2) = 0.14$, $e(\vartheta_3) = 0.12$, $e(\vartheta_4) = 0.2$, $e(\vartheta_5) = 0.13$, $e(\tau_6) = 0.12$

Let the capacities (hr/day) be given as:

$$C_1 = 16,\ C_2 = 16,\ C_3 = 40,\ C_4 = 32,\ C_5 = 40,\ C_6 = 40.$$

Let the transition time (days) be given as the following with estimations:

$m(M_0) = 2.0$, $m(M_{10}) = 1.0$, $m(M_{21}) = 3.0$, $m(M_{31}) = 2.0$, $m(M_{41}) = 3.0$, $m(M_{52}) = 2.0$, $m(M_{65}) = 3.0$,

and the degree of ambiguities:

$e(M_0) = 0.5$, $e(M_{10}) = 0.5$, $e(M_{21}) = 3.0$, $e(M_{31}) = 0.25$, $e(M_{41}) = 0.17$, $e(M_{52}) = 0.25$, $e(M_{65}) = 0.17$.

Let the transition time (days) for the external suppliers be given as the following with estimations:

$m(M_{s_{1,1}}) = 4.0$, $m(M_{s_{2,1}}) = 5.0$, $m(M_{s_{3,6}}) = 4.0$, $m(M_{s_{4,3}}) = 3.0$, $m(M_{s_{5,3}}) = 5.0$, $m(M_{s_{6,3}}) = 4.0$, $m(M_{s_{7,3}}) = 2.0$, $m(M_{s_{8,4}}) = 3.0$,

and the degree of ambiguities:

$e(M_{s_{1,1}}) = 0.25$, $e(M_{s_{2,1}}) = 0.2$, $e(M_{s_{3,6}}) = 0.25$, $e(M_{s_{4,3}}) = 0.17$, $e(M_{s_{5,3}}) = 0.2$,

$e(M_{s_{6,3}}) = 0.25$, $e(M_{s_{7,3}}) = 0.25$, $e(M_{s_{8,4}}) = 0.17$.

According to (5.4), we get that

$$m(S_1) = m(\overline{d}) \times (T_1 + \max\{m(M_{21}), m(M_{31}), m(M_{41}), m(M_{s_{1,1}}), m(M_{s_{2,1}})\} + $$
$$+ m(\overline{d}) \times T_1 \times m(\tau_1) \times (1 + m(\varphi_1) \times m(\vartheta_1)) / C_1)$$
$$= 200 \times (3 + \max\{3.0, 2.0, 3.0, 4.0, 5.0\} + 200 \times 3 \times 0.042 \times (1 + 0.0013 \times 2) / 16) = 1916$$
$$e(S_1) = \max\{\max\{e(M_{21}), e(M_{31}), e(M_{41}), e(M_{s_{1,1}}), e(M_{s_{2,1}})\}, e(\overline{d}), e(\tau_1), e(\varphi_1), e(\vartheta_1)\}$$
$$= 0.5.$$

$$m(S_2) = w_2 \times m(\overline{d}) \times (T_2 + m(M_{52}) + m(\overline{d}) \times w_2 \times T_2 \times m(\tau_2) \times (1 + m(\varphi_2) \times m(\vartheta_2)) / C_2)$$
$$= 200 \times (4 + 2.0 + 200 \times 4 \times 0.02 \times (1 + 0.0014 \times 2.2) / 16) = 1401;$$
$$e(S_2) = \max\{\max\{e(M_{52})\}, e(\overline{d}), e(\tau_2), e(\varphi_2), e(\vartheta_2)\} = 0.5.$$

$$m(S_3) = m(\overline{d}) \times (T_3 + \max\{m(M_{s_{4,3}}), m(M_{s_{5,3}}), m(M_{s_{6,3}}), m(M_{s_{7,3}})\} +$$
$$+ m(\overline{d}) \times T_3 \times m(\tau_3) \times (1 + m(\varphi_3) \times m(\vartheta_3)) / C_3)$$

$$= 200 \times (3 + \max\{3.0, 5.0, 4.0, 2.0\} + 200 \times 3 \times 0.03 \times (1 + 0.0013 \times 2.3) / 40) = 1690$$

$$e(S_3) = \max\{\max\{e(M_{s_{4,3}}), e(M_{s_{5,3}}), e(M_{s_{6,3}}), e(M_{s_{7,3}})\},\ e(\overline{d}),\ e(\tau_3),\ e(\varphi_3), e(\vartheta_3)\}$$
$$=0.5$$

$$m(S_4) = m(\overline{d}) \times (T_4 + \max\{m(M_{s_{8,4}})\} + m(\overline{d}) \times T_4 \times m(\tau_4) \times (1 + m(\varphi_4) \times m(\vartheta_4)) / C_4)$$
$$= 200 \times (3 + 3.0 + 200 \times 3 \times 0.033 \times (1 + 0.0015 \times 1.9) / 32) = 1324;$$
$$e(S_4) = \max\{\max\{e(M_{s_{8,4}})\},\ e(\overline{d}),\ e(\tau_4),\ e(\varphi_4), e(\vartheta_4)\} = 0.5.$$

$$m(S_5) = m(\overline{d}) \times (T_5 + \max\{m(M_{s_{6,5}})\} + m(\overline{d}) \times T_5 \times m(\tau_5) \times (1 + m(\varphi_5) \times m(\vartheta_5)) / C_5)$$
$$= 200 \times (4 + 3.0 + 200 \times 4 \times 0.032 \times (1 + 0.0017 \times 3) / 40) = 1529;$$
$$e(S_5) = \max\{\max\{e(M_{s_{6,5}})\},\ e(\overline{d}),\ e(\tau_5),\ e(\varphi_5), e(\vartheta_5)\} = 0.5.$$

$$m(S_6) = m(\overline{d}) \times (T_6 + \max\{m(M_{s_{3,6}})\} + m(\overline{d}) \times T_6 \times m(\tau_6) \times (1 + m(\varphi_6) \times m(\vartheta_6)) / C_6)$$
$$= 200 \times (5 + 4.0 + 200 \times 5 \times 0.028 \times (1 + 0.0015 \times 2.5) / 40) = 1941;$$
$$e(S_6) = \max\{\max\{e(M_{s_{3,6}})\},\ e(\overline{d}),\ e(\tau_6),\ e(\varphi_6), e(\vartheta_6)\} = 0.5.$$

Since the root-site c_0 is a non-production site, we have that

$$m(S_0) = m(\overline{d}) \times (T_0 + m(M_{10})) = 600;$$
$$e(S_0) = e(M_{10}) = 0.5.$$

According to (4.24), the optimal and the pessimistic order-up-to levels for the pre-specified rate $r = 0.95$ at the sites c_j, $j = 1, 2, \cdots, 6$, are given as:

$$S_1^o = (1 - e(S_1) + r \times e(S_1)) \times m(S_1) = 1{,}868;$$
$$S_1^p = (1 + r \times e(S_1)) \times m(S_1) = 2{,}826.$$
$$S_2^o = (1 - e(S_2) + r \times e(S_2)) \times m(S_2) = 1{,}366;$$
$$S_2^p = (1 + r \times e(S_2)) \times m(S_2) = 2{,}066.$$
$$S_3^o = (1 - e(S_3) + r \times e(S_3)) \times m(S_3) = 1{,}648;$$
$$S_3^p = (1 + r \times e(S_3)) \times m(S_3) = 2{,}493.$$
$$S_4^o = (1 - e(S_4) + r \times e(S_4)) \times m(S_4) = 1{,}291;$$
$$S_4^p = (1 + r \times e(S_4)) \times m(S_4) = 1{,}953.$$

$$S_5^o = (1 - e(S_5) + r \times e(S_5)) \times m(S_5) = 1{,}491;$$

$$S_5^p = (1 + r \times e(S_5)) \times m(S_5) = 2{,}255.$$

$$S_6^o = (1 - e(S_6) + r \times e(S_6)) \times m(S_6) = 1{,}892;$$

$$S_6^p = (1 + r \times e(S_6)) \times m(S_6) = 2{,}863.$$

At the root site c_0, the optimal and the pessimistic order-up-to levels at c_0 are

$$S_0^o = (1 - e(S_0) + r \times e(S_0)) \times m(S_0) = 585;$$

$$S_0^p = (1 + r \times e(S_0)) \times m(S_0) = 885.$$

Thus the order-up-to levels in all sites of supply chain can be easily calculated.

7. Conclusion

As a supplement on fuzzy supply chain analysis, this chapter presents modeling for supply chain problems. In particular it answers question such as the following to the readers:

1. How to estimate parameters with fuzziness in supply chains? How to imitate experts' experiences as an estimation process? How to change our used subjective approach to be an acceptable subjective way?
2. How to define the arithmetic operations for fuzzy parameters? How to abandon the prudent principle of classical mathematics and accept the decisive principle in subjective estimation? What is the direction to prevent the uncertainty-increasing during performing arithmetic operations on fuzzy parameters?
3. How to treat fuzzy parameters when the randomness and fuzziness occur simultaneously?
4. How to simplify the complex analysis of supply chain? What is a simple chain? What is a stationary supply chain? How to get some formulae to calculate the order-up-to levels in a stationary simple chain? How to extend the advantages of pure mathematical analysis to the general cases?

From the answers to these questions presented in this chapter, the reader will find out new aspects and new considerations. It will be helpful to reflect by asking this question again: Where is the purpose of this chapter in the book? Yes, it is a supplement of fuzzy supply chain analysis. But, in some sense, it is also a supplement of non-deterministic supply chain analysis. In some other sense, it is also a supplement of the pure mathematical analysis on supply chains.

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11

Fuzzy Multiple Agent Decision Support Systems for Supply Chain Management

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1. Introduction

A supply chain encompasses the processes from the initial materials provision to the ultimate consumption of finished product linking across supplier-user companies. It involves the functions within and outside a company that enable the value chain to make products and provide services to the customers (Handfield & Nicholas, 1998). Supply chain management (SCM) is a strategic approach, which contains the following processes (Rogers, 2003): (i) Customer relationship management; (ii) Customer service management; (iii) Demand management; (iv) Order fulfillment; (v) Manufacturing flow management; (vi) Procurement; (vii) Product commercialization; and (viii) Returns management.

Graves & Willems (2000 and 2000) developed an optimization algorithm to find the best inventory levels of all sites on the SC. They also extend their model to solve the supply chain configuration problems for new products. Cebi & Bayraktar (2003) proposed an integrated lexicographic goal programming (LGP) and AHP model including both quantitative and qualitative conflicting factors for supply chains. Wang et al. (2004) presented a weighted multiple criteria model for SC. They stated that in real world problems, the weights of different criteria may vary based on purchasing strategies. Stadtler (2005) presents the main difficulties of SCM and tries to present some new models to resolve them. Baganha & Cohen (1998), Graves (1999), Chen et al. (2000), and Li et al. (2005) study the demand updating and information sharing issues of SC. Cachon (1999), and Kelle & Milne (1999) study the order batching in supply chain.

Li et al. (2005) use the term information transformation to describe the phenomenon where for each considered stage, outgoing orders to higher stage of a supply chain have different variance from incoming orders that each stage receives.

By the emergence of the new tools in information and communication technologies, globalization and shifting from mass production to mass customization, new requirements for achieving competitive advantages in supply chain management have been defined. These changes lead to the next generation of supply chain management systems. Such systems must have at least some essential characteristics, such as: agility, responsiveness, adaptability, integrated and cooperative [Lembert et al. 1998; Verdicchio & Colombelte 2000). The most effective areas that have drastically changed SCM are distributed artificial intelligence and agent-based systems.

In the literature, there are some research manuscripts that show distributed artificialintelligence (DAI), especially agents and multi-agent systems (MAS), for SC (Simchi-Levi et al. 2000; Wu et al. 2000). Multi-agent systems paradigm is a valid approach to model supply chain networks and for implementing supply chain management applications. Multi-agent computational environments are well-suited for analyzing coordination problems, involving multiple agents with distributed knowledge. Thus, a MAS model seems to be a natural choice for the next generation of SCM, which is intrinsically dealing with coordination and coherent among multiple actors (Wu et al. 2000; Shen et al 2001). The inherent autonomy of software agents enables the different business units of supply chain network to retain their autonomy of information and control, and allows them to automate part of their interactions in the management of a common business process (Fazlollahi, 2002). As uncertainty in the environment of supply chain is usually unavoidable, an appropriate system is needed to handle it. Fuzzy system modeling has shown its capability to address uncertainty in supply chain. It can be used in an agent-based supply chain management system by development of fuzzy agents and fuzzy knowledge-base; Fuzzy agents use fuzzy knowledge bases, fuzzy inference and fuzzy negotiation approaches to handle the problems in the environment and take into consideration uncertainty. Using fuzzy concepts leads to more flexible, responsive and robust environment in supply chain which can handle changes more easily and cope with them naturally.

Erol & Ferrel (2003) discussed applications of fuzzy set theory in finding the supplier with the best overall rating amomg suppliers. Fazel Zarandi & Saghiri (2006) presented a fuzzy expert system model for SC complex problems. They compared the results of their proposed expert system model with fuzzy linear programming and showed its superiority. Zarandi et al. (2005) presented a fuzzy multiple objective supplier selection's model in multiple products and supplier environment. In their model, all goals, constraints, variables and coefficients are fuzzy. They showed that with the application of fuzzy methodology, the multi-objective problem is converted to a single one.

2. Multi agent systems and agent-based supply chain management

Software agents are just independently executing program, which are capable of acting autonomously in the presence of expected and unexpected events (Fox et al. 1993). To be described as intelligent, software agents should also process the ability of acting autonomously, that is, without human input at run-time, and flexibly, that is, being able to balance their reactive behavior, in response to changes in their environment, with their proactive or goal-directed behavior (Hayzelden & Bourne 2001). These issues have also been discussed by other authors, which were classified by Liu et al. (2000).

As stated by Fox et al. (1993), in the context of multiple autonomously acting software agents, the agents additionally require the ability to communicate with other agents, that is, to be social. The ability of an agent to be social and to interact with other agents means that many systems can be viewed as multi-agent systems (MAS). The hypothesis or goal of multi-agent systems is: creating a system that interconnects separately developed agents, thus, enabling the ensemble to function beyond the capabilities of any singular agent in the systems.

In multi-agent systems, some issues such as: agent communications, agent coordination, and inference must be considered (Nwana & Ndumu 1999). For agents to communicate with each other, an agent communication language (ACL) is needed. Multi-agent systems have been applied in supply chain management and they have introduced a new approach called agent-based supply chain management. In an agent-based supply chain management, the supply chain is considered as being managed by a set of intelligent software agents, each responsible for one or more activities in the supply chain, and each interacting with other agents in the planning and execution of their responsibilities.

For applying agents in supply chain management, first, the following issues must be considered (Lambert et al. 1998; Verducchio & Colombetti 2000; Fazlollahi 2002):

i. The distribution of activities and functions between software agents;
ii. Agent communication issues, including: Interoperability, Coordination, Multi-agent scheduling and planning, Cultural assumption;
iii. Responsiveness; and
iv. Knowledge accessibility in a module.

During the past decade, agent based supply chain management has been the main concern of many researchers. Saycara (1999) has done related projects and research in this area. Lambert et al. (1998) introduce virtual supply chain management and virtual situation room in which agents are the main elements for achieving a coordinated and cooperated supply chain. Jiao et al. (2006) propose the use of multi-agent system concepts in global supply chain networks. Xue et al. (2005) suggest a framework for supply chain coordination in a construction networks. Wang & Sang (2005) present a multi-agent framework for the logistics in a supply chain network. Fox & Barbuceanu (2000) discuss a model for agent negotiation and conversation in an agent based supply chain management. Dasgupta et al. (1999) focus on the negotiation between suppliers in different stages in supply chain management. Chauhan (1997) and Lau et al. (2000) propose a methodology for multi-agent systems development in supply chain. Chauhan (1997) used Java technology and objectoriented approach to achieve the goal. Lau et al. (2000) introduce a methodology for a flexible workflow system in supply chain to obtain more flexibility in ever changing environment of supply chain.

Some researchers present some architecture for agent based supply chain management. Ulieru et al. (1999) introduced a common architecture for collaborative Internet based systems in which some services are delivered via Internet. The architecture was for coordinated development of planning and scheduling solutions. The architecture proposed by Yung & Yang (1999) is composed of functional and information agents for reducing bull wipe effect in supply chain. Fox & Barbuceanu (2000) have proposed an architecture for agent based supply chain management composed of functional and information agents. They have also introduced a common building shell for agent structure in supply chain management.

Wu et al. (2000) focuses on web centric and Internet based supply chain management. They concentrate on service delivery via collaborative agents in the internet and propose a common and integrated framework for web-centric supply chain management systems. EDS Group (Wu et al. 2000) applies web technology for developing a networked society for each partner in supply chain. The group uses Java technology for internet-based purchasing and contracting.

In literature, we can hardly find research papers and project manuscripts that concentrate on uncertainty in supply chain, specialized information distribution and flexibility. According to the existing uncertainty in supply chain environment, using an approach which can address these problems seems necessary. As each partner in supply chain has its own needs and information requirements, distributing information according to the requirement of each partner is a critical factor, which a few research focused on it. Achieving flexibility is supply chain environment is one of the main concerns of the past decade. Using fuzzy agents and creating a flexible environment in supply chain can handle major issues relating to coordination and collaboration and can address flexibility problems in supply chain. The main concern of this research is focusing on these important issues.

3. ISCM model

Integrated Supply Chain Management (ISCM) system proposed by Fox & Barbuceanu (2000) encompasses a whole architecture and a general agent building shell for all agents in an agent-based supply chain management. ISCM is a multi-agent approach in which supply chain is considered as a set of six functional and two information agents that cooperate with each other to fulfill their goals and functions. The architecture of ISCM is shown in Figure 1.

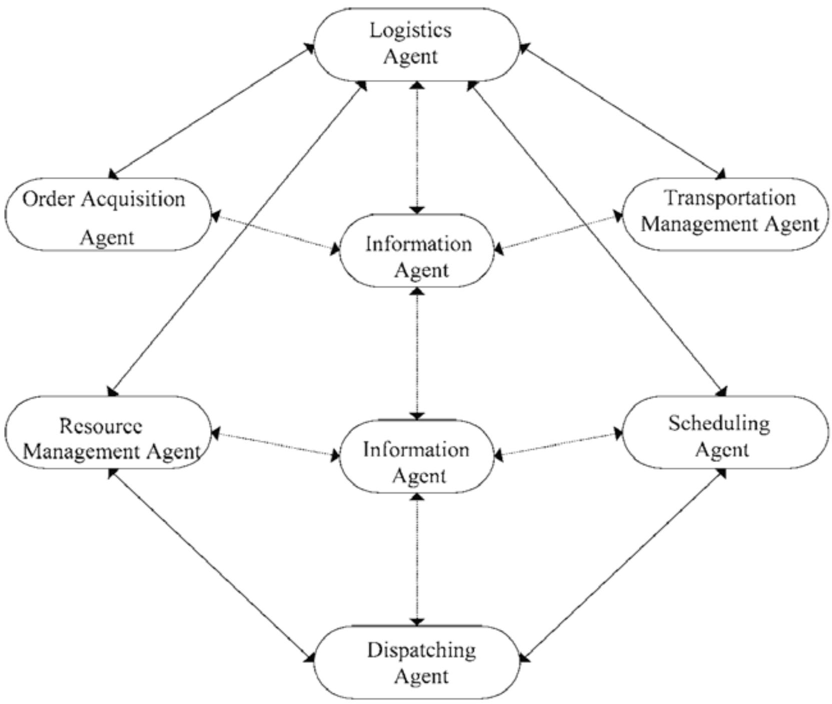

Figure1. ISCM Architecture

Functional agents, including logistics, order acquisition, transportation management, resource management, scheduling and dispatching have specific functions and interact with others to achieve the supply chain goals. Information agents support functional agents to access updated information and knowledge in supply chain. They eliminate conflicts in information resources, process the information in order to determine the most relevant content and the most appropriate form for the needs of agents and provide periodical information for them. Information agents provide other agents a layer of shared information storage and services. Agents periodically volunteer some of their information to the information agents or just answer the queries sent to them by the information agent (Fox et al., 1993; Fox & Barbuceanu 2000).

This paper focuses on the architecture of information agent in ISCM. For this purpose, we explain its functions, inputs and outputs. Then, by considering the basics of a modular architecture for agents and also supply chain properties, a new modular architecture for the information agent in ISCM is proposed. We develop the knowledge-base in the architecture and define required fuzzy rules and database. Moreover, we evaluate and test the knowledge base and compare the method in which fuzzy rules has been used with the one with non-fuzzy rules. Finally, we introduce an approach for dynamic updating the forecasted cost and time in every stage of supply chain.

An information agent is responsible for providing transparent access to different resources, as well as retrieving, analyzing and eliminating inconsistency in data and information, properly (Klusch, 1999). It is a computer software system that accesses to different geographically distributed and inconsistent multi resources and assists users and other agents to provide relevant information. In other words, information agents manage information access issues (Nwana, 1996). Depending on the ability of information agent to cooperate with each other for the execution of their tasks, they can be classified into two broad categories: *Non-cooperative* and *cooperative*. An information agent, cooperative or noncooperative, can be relational, adaptive or mobile. Relational information agents behave and may even collaborate together to increase their own benefits and they are utilitarian in an economic sense. Adaptive information agents are able to adapt themselves to changes in the networks and information environments. Mobile information agents are able to travel autonomously through a network (Klusch, 1999).

According to the changes in a supply chain, an agent must be able to adapt with uncertainty and incomplete information. An approach to obtain a flexible behavior for an information agent is to form a team of agents which are cooperative and are capable of gradual adaptation. Adaptive information agents can fulfill this goal. This research uses adaptive information agent to cope with changes in supply chain environment and achieve more flexibility and robustness.

The main function for an information agent is to process information retrieval requests and information monitoring, intelligently and efficiently. Generally it can be said that an information agent is able to provide essential services related to human and agents' information requirements. However, there is a difference between an information agent and a web service provider. An information agent can infer about the method for analyzing requests and how they must be processed (Caglayan & Harrison 1997). Therefore, we can consider three main functions for a typical information agent (Barbaceanu & Fox 1995): (i) Knowledge management; (ii) Eliminating conflict management; and (iii) Supporting coordination between other agents.

According to different resources (Fox et al. 1993; Barbuceanu & Fox 1995; Sycara 1999) and also the supply chain environment and features, we have considered six functions for the information agent in supply chain management:

- Storing the required information for sharing and providing a layer of information;
- Analyzing information for providing the proper respond to queries and requests;
- Automate routing for information distribution;
- Conflict management;
- Change management;

- Negotiating with other agents to provide essential information;

The inputs of an information agent can be categorized into queries and changes. Requests are those that are sent by other agents and information agent considers changes in the environment by receiving the changes. Responses to the requests and queries are possible outputs of the information agent. An information agent should automatically direct the essential information to the agents. Periodical information for other agents can be another type of output. Also, an information agent should recognize that which agent can access to what information. Consequently, one possible output should issue this function. Finally, an information agent must share some information between groups of agents. The output of this function can be the required shared information

According to the above inputs, functions, and outputs of the information agent in supply chain management, this chapter proposes a new architecture for the information agent. A conceptual model for an agent has four main parts: reasoning engine, knowledge base,learning engine and access control. Reasoning engine determines the required actions for the acquired events and knowledge from the environment. Knowledge-base stores the information and knowledge used by reasoning engine. Access control is an interface with the environment. Feedbacks are received by access control and actions are sent to the environment.

5. Modules of the proposed system

This section explains the goals, features, method, and structure of each module in the proposed architecture.

5.1 Conflict management

An information agent can have access to different information resources and receive different type of data. There must be a module to remove the possible conflicts and inconsistency between information. Thus, before considering any changes or information in the knowledge-base and informing others about this, conflict management module must eliminate any inconsistency or conflict with the existing information. For this purpose, we have used a-u space model (Barbuceanu & Fox 1995).

Suppose that we have a conflict between expression *p* and *q*. Expression *p* is the input statement and expression *q* is an existing statement. To each *p* we can attach an authority measure--the authority of its producer—and a un-deniability measurederived from the sum of deniability costs of all propositions that would have to be retracted if *p* is retracted. A high authority means that the proposition is more difficult to retract since a high authority has to be contradicted. A high un-deniability means that the proposition is more difficult to retract because the costs of retraction incurred upon consumer agents will be high (Barbuceanu & Fox 1995). We can represent these two values of all *p* as points in a diagram, having authority on the x-axis and undeniability on the y-axis. Such a diagram is called "a-u" space and is illustrated in Figure 2.

We can summarize the evaluation of a-u space in four rules as follows:

Rule 1 - If $a < a_t$ AND $u < u_t$ THEN Status = No Negotiation

Rule 2 - If $a < a_t$ AND $u > u_t$ THEN Status = Negotiation with Consumers

Rule 3 - If $a > a_t$ AND $u < u_t$ THEN Status = Negotiation with Producer

Rule 4 - If $a > a_t$ AND $u > u_t$ THEN Status = Negotiation with both

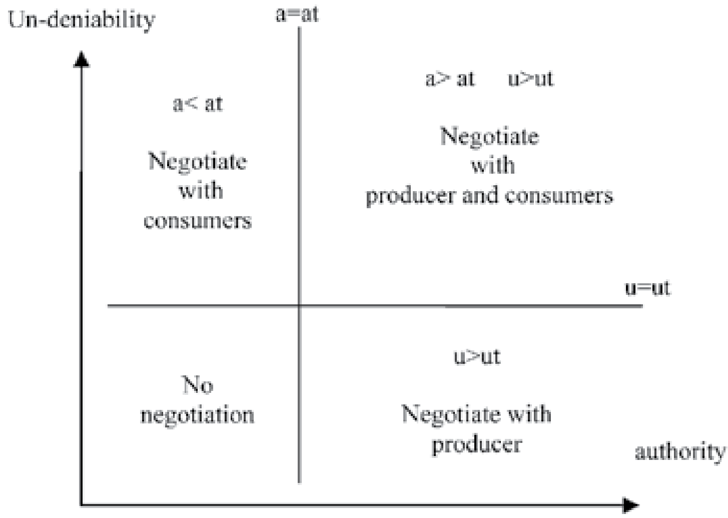

Figure 2. Negotiation regions in a-u space

Using fuzzy concepts in the proposed architecture, the following fuzzy rules are presented:
Rule 1 - If a isr Low AND u isr Low THEN Status is No negotiation
Rule 2 - If a isr Low AND u isr High THEN Status is Negotiation with consumer
Rule 3 - If a isr High AND u isr Low THEN Status is Negotiation with producer
Rule 4 - If a isr High AND u isr High THEN Status is Negotiation with Both
where, "High" and "Low" are linguistic values, each have its related membershipfunction, and “isr” stands for “is related to”.

5.2 Knowledge-base

The knowledge-base is responsible for storing data and knowledge. Knowledge- base comprises of two parts: rule-base and database. Rule-base contains a number of Metarules and subsets of rules. The rules are in both fuzzy and crisp format. Database stores data and information acquired from other external resources or new information generated by learning and tendering modules. The membership functions of linguistic values for fuzzy rules are also stored in the database.

5.3 Inference engine

Inference engine is one of the most important parts of an agent base system. Reasoning and deduction process are arranged by inference engine. Based on the situation of the inputs, the engine fires the rules in rule-base as a matter of degree and determines the proper fuzzy output.

5.4 Tendering

As information agent may not have essential knowledge to provide proper answer to some queries. We have set a tendering module in the architecture to avoid leaving a query without any response. The information agent can negotiate with other agents to find appropriate answer for a query which it does not have the required knowledge to answer.

Thus, it can use tendering process to discover the response. For organizing tendering process we have used brokering method (Klusch 1999). We differentiate among three types of agents in brokering method:

1) *Provider agents* provide their capabilities to their users and other agents.
2) *Requester agents* consume information and services offered by provider agents in the system. Requests for provider agent capabilities have to be sent to a middle agent.
3) *Middle agents*, i.e., broker agents, mediate among requesters and providers for some mutually beneficial collaboration. Each provider must first register itself with one (or multiple) middle agent. Provider agents advertise their capabilities (advertisement) by sending some appropriate messages describing the kind of service they offer.

The broker agent deals with the task of contracting the relevant providers, transmitting the service request to the service provider and communicating the results to therequester. When there is not enough knowledge to respond to a request or query, the information agent uses the tendering module to find the appropriate respond. In this occasion, the information agent is a broker agent and the requester agent is the agent that inquires and the provider agent is the agent that provides the appropriate answer for the inquiry.

5.5 Learning

Learning ability for an agent determines degree of its intelligence (Klusch 1999). This module creates new knowledge and reduces existing errors in the current knowledge. In this research, a Neural Network (NN) is implemented for learning. This net can improve the forecasted amount, cost or time, by using an error reduction function. In this case, learning is done for long term data, and for error reduction of short term, the NN uses the rules in the rule-base. More detail for this module is as follows:

In the information agents, learning implies the agent's ability to automatically modify the rule-base and the facts in two ways:

- Adding new rules or modifying existing rules: if the information agent can recognize a desirable new behavior, it may be able to propose a new rule about it. Also, it can modify existing rules, which is a form of rule optimization. Tendering module handles the queries where there is not proper answer for them. The learning engine can add a new rule or modify the existing ones to consider the result of tendering in rule-base. Consequently, if the query repeats again, there is no need for tendering, because the learning engine has created the proper knowledge. Also, information agent can recognize the periodical needs of every agent as they request for some information by the use of learning engine. Learning engine can also change the certainty factors of fuzzy rules, if required.
- Adding new facts or modifying old facts: changing and improving forecasted values are a critical issue in supply chain. The learning module can update forecasted values, e.g., costs and time, and reduce the errors by fuzzy neural networks.

5.6 Distributed data warehouse and data marts

For sharing the information between other agents and making required access to the information and data, we have set a Distributed Data Warehouse (DDW). A DDW is a logically integrated collection of shared data that is physically distributed across the nodes of a computer network (Moeller 2001). Traditional data warehouses, which are not distributed, are not appropriate for this purpose, because:

- According to huge interaction of data, designing and developing a single traditional data warehouse is hardly possible.
- Traditional data warehouses usually are designed for predetermined requests, but, here, we can not determine the requests exactly.
- Traditional data warehouses response time and loading are much more than DDW.
- As information agent interacts with different type of agents, it has to provide different kind of information specified for each agent. Thus, a DDW composed of different data mart is appropriate in this case.
- In occasions that the information is distributed naturally, like supply chain, DDW can be the best solution.

A DDW is composed of different data marts, where each is responsible for providing the information related to a specified area. A data mart is an application-focused miniature data warehouse, built rapidly to support a single line of business. Data marts share all the other characteristics of a data warehouse (Zarandi et al 2005). The data marts are independent, which can operate without a support of a centralized DDW. These kinds of data marts receive data and information directly from the resources, and give service to the consumers. As the information agent give services to four different agents, including Order Acquisition, Logistics, Transportation Management, and information agent, we generate a DDW with 4 data marts. Each data mart is responsible to provide information services for each agent. Database and data marts in this architecture communicate with each other by the use of ORB technology. An Object Request Broker (ORB) is a middleware that establishes the client-server relationships between objects. It provides a mechanism for transparently communicating the client requests to servers. ORB is an attempt to distribute computing across multiple platforms. Using an ORB, a client can transparently invoke a method on a server object, which can be on the same machine or across a network. The ORB intercepts the call and is responsible for finding an object that can implement the request, passing it the parameters, invoking its method, and returning the results. The client does not have to be aware of where the object is located, the programming language in which it is written, the operating system it is running on, or any other implementation details that are not part of the object's interface. Thus, the ORB provides interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems. The leading example of this approach is the Common Object Request Broker Architecture (CORBA).

5.7 Normalization, fuzzification and defuzzification

We have used Mamdani type operators to fuzzify the variables and aggregation of the rules, stated in (Cordon 2001). Mamdani fuzzy reasoning takes the minimum of the antecedent conditions in each rule and assumes the fuzzy truth of the rule to be 1. We use minimum operator for rule implications and AND operator in antecedent of rules. From a functional point of view, a Mamdani fuzzy inference system is a nonlinear mapping from an input domain $X \in R_n$ to an output domain $Y \in R_m$. This input/output mapping is realized by means of R rules of the following form:

$$\text{IF } x \text{ isr } A(\text{r}) \text{ THEN } y \text{ is } B(\text{r}) \qquad (1)$$

where, $r = 1,2,\ldots,R$ is the index of the rule, while $A\ (r)$ and $B\ (r)$are fuzzy relations over X and Y respectively. When an input vector x is presented to the system, a fuzzy set B is inferred according to the following relation:

$$B(y) = \vee\ (A_{(r)}(x) \wedge B_{(r)}(y)) \qquad (2)$$

where, the formalism A (●) denotes the membership function of a fuzzy set A , and ∧,∨ are a T-norm and a T-conorm, respectively (usually the min and the max operators are used).
Center of gravity method has been used for defuzzification method, Defined as:

$$\hat{y} = \frac{\int B(y).y.dy}{\int B(y).\ dy} \qquad (3)$$

As the input information and data are not in the same scale, there must be a module to standardize them and turning them into one form. Therefore, we use a normalization method to standardize input information and data. For normalizing a set of input information and data, the data is divided by the larges one in the set.

6. Developing database

As described earlier, database contains two types of data: data and information related to supply chain and membership functions of the linguistic values. We have used relational approach to develop the database. For storing the data and information related to supply chain, a model is considered for order fulfillment in which a supply chain is viewed as the composition of different stages.
It should be noted that, for an order fulfillment, some certain stages must be taken (Hanfield & Nichols 1998; Rogers 2003; Simchi-Levi 2000). For taking each stage, there are different methods. Therefore, by composing different methods for each stage, there will be different routes to fulfill an order. Each method in each stage has three features: method name, method cost, and method time (duration). Consequently, a route for an order has three features: route name, route cost (order total cost), and route time (order total time). Route cost and route time of an order are respectively the sum of cost and time of all stages in the route. There are two values for time and cost of each method in every stage: forecasted value and actual value. Order properties and related information such as customer properties, due date, order time, and the like are stored in the database. In addition to the mentioned information, any information agent can store any type of information receiving from the other agents.
There are five different linguistic values for measuring the degree of changes and weights: Very Low, Low, Medium, High, and Very High.

7. Developing rule-base

The rule-base in the knowledge base has 31 rules, 3 Meta rule and 3 rule subsets. Rule-base contains both fuzzy and crisp rules. As mentioned before, every order has its related total time and total cost which can be obtained respectively by adding time and cost of each stage in the order route. We introduce an approach for updating the forecasted values of total time and cost of each order and directing the supply chain to the committed cost and time

for the costumer. Before an order flows in the supply chain, there is forecasted total time and total cost for order fulfillment. As the order moves in the chain and goes through the stages, the actual cost and time for each stage are emerged. Consequently, we can define new total time and total cost for the order. Thus, if order *a* needs *m* stages to be fulfilled, we have:
Total time for *a:*

$$TotalTime(a) = \sum_{i=1}^{m} TimeStage_i(a) \tag{4}$$

Total cost for *a:*

$$TotalCost(a) = \sum_{i=1}^{m} CostStage_i(a) \tag{5}$$

where, *TimeStagei* (*a*) is the duration of stage *i* and *CostStagei* (*a*) is the cost of stage *i* of order *a*. If the time of stage *k* changes to *T,* then total time of *a* changes to:

$$TotalTime(a) = \sum_{i=1}^{m} TimeStage_i(a) + (T - TimeStage_k(a)) \tag{6}$$

Generally, in stage i of m we have i total time and i total cost for a. Thus, we have m total time and m total cost for order a at the end of order fulfillment. We have used different total time and total cost in every stage to forecast the next value in the chain. By comparing forecasted value in every stage and the initial forecast value, which is the committed value to the costumer, the partners in the chain will be notified about the difference between the committed value and the real one and consequently they change their plan and behavior in a manner to reach the committed value.

8. Determination of the forecasted value

Assume that we are at stage *i* of order *a*. Thus, we have *i* total time as follows:
Total time of *a* in stage *i*:

$$TotalTime^{(i)}(a) = T_i \tag{7}$$

Then, we can use fuzzy rules to define a weight for each total time, for example:
IF ($Tk - Tk - 1$) isr Low AND ($Tk - 1 - Tk - 2$) isr High THEN $Weight(Tk)$ isr Medium where, $Weight(Tk)$ is the weight of T_k and "isr" means "is related to". The forecasted value for total time in stage *i* is:

$$T = \sum_{k=1}^{i} T_k Weight(T_k) \tag{8}$$

9. Technical issues, implementation and validation

The proposed common structure for agents in supply chain by Fox & Barbuceanu (2000) is composed of seven layers which are: agent communication language, conversational coordination, action and behavior, organization model, decision making, behavior planning, behavior execution and domain specific solvers. The structure is considered for all agents in the agent-based supply chain management, including information and functional agents. Also they proposed some essential features for an information agent as follows (Fox & Barbuceanu 2000):

- Change management
- Query management
- Conflict management
- Time map management system.

The proposed architecture in this section has eight modules. These modules satisfy the expected functions and output from the information agent. Normalization module standardizes the input data and changes their format in such a manner that their comparison makes sense. Fuzzification module fuzzifies the information to infer and use it in knowledge base. Using fuzzy rules, increases system flexibility and robustness and reduces complexity, thus, information agent can handle uncertain events and information more easily. Conflict management eliminates the existing conflicts and inconsistency between data and information by using a-u space model with fuzzy boundaries. Knowledge-base stores current and new knowledge including rules and data. Tendering module avoids leaving a query without any response, and information agent negotiates with other agents to find proper answer for any query that it can not response individually. Learning module modifies existing rules and facts and eventually creates new rules and facts according to the current information, events and agents behavior. For sharing the information and data specifically for every agent, a DDW module has been applied. The DDW contains four data marts, each responsible to provide specialized information and services for a particular agent. Defuzzification module changes the fuzzy information to crisp information to share with other agents. For testing the rule-base and comparing the result of applying fuzzy rules, a set of data related to a Computer Monitor supply chain has been used. All the proposed rules and their related databases have been assessed and suitable responses have been gained from their assessment, based on the negotiations with experts.

10. Bullwhip reduction in SC

One of the most fruitful research sub-areas in studying supply chain management is bullwhip effect or whiplash effect. The bullwhip effect occurs when the demand order variations in the supply chain are amplified as they move up in the supply chain. Five possible sources for bullwhip effect are recognized in the literature (Lee et al. 1997a) and (Lee et al. 1997b). They include: demand forecast updating, prize fluctuation, rationing and shortage gaming, order batching and none-zero lead time. The first formal description of the bullwhip effect can be traced back to the work of Forrester (Forrester 1961). Sterman (1989) further demonstrates and discusses this phenomenon in the popular beer game. According to Sterman (1989), the bullwhip effect originates from the non-optimal solutions adopted by a supply chain participant while it does not consider the system as a whole. In the recent works, Cachon & Lariviere (1999) study the shortage gaming; Kelle & Milne (1999) and Cachon (1999) study the order batching and Drezner et al. (2000), Baganha & Cohen (1998), Graves (1999), Chen et al. (2000) and Li et al. (2005) study the demand updating and information sharing issues. Li et al. in (2005) use the term information transformation to describe the phenomenon, where for each of the stages considered, outgoing orders from a lower to a higher stage of a supply chain has a different variance from incoming orders which each stage receives.

However, there is only one work (Carlsson & Fuller 2001a) that applied fuzzy logic related concepts to bullwhip effect. Based on an optimal crisp ordering policy that drives the bullwhip effect, they presented a policy in which orders are imprecise. In an environment where orders can be intervals, they allow the actors in the supply chain to make their orders more precise as the time of delivery gets closer. They show that if the member of the supply chain share information with intelligent support technology, and agree on better and better fuzzy estimates on future sales for the upcoming periods the bullwhip effect can be significantly reduced. However, they did not consider the uncertainty in the demands and lead times in their proposed model.

As a matter of fact, for analyzing the Bullwhip Effect in the real world, one should consider it in an uncertain environment. In this research, Fuzzy Logic is utilized as a mean to represent and interpret the uncertainty in the real world supply chains. Thus, we propose to study the effect of fuzziness, i.e., information uncertainty, on the bullwhip effect. Here, it is assumed that all demands, lead times and order quantities have fuzzy values, i.e., they are imprecise. Among the available fuzzy time series approach, the Hong method (Hong 2005) is selected and a Genetic Algorithm (GA) module is added to obtain the value of window basis. In addition, a back propagation Neural Network module is added to defuzzify the output of Hong's model. In this paper, an Agent-Based model is developed to reduce the bullwhip effect in the above mentioned situation. Geary et al. (2005) categorized all previous approaches for reducing the bullwhip effect into five categories: OR Theory, Filter Theory, Control Theory, Adhocacy, and What-if simulation procedure. The proposed solution is a combination of OR Theory and What-if simulation approaches.

10.1 A problem sample

Consider a single item multi stage supply chain system in which only one participant exists at each stage. The participant's actions at a given stage *k* are described as follows:

At the end of time period *t*, after its demand $\widetilde{D}k,t$ has been realized, the participant observes the inventory level, places an order of size $\widetilde{Y}k,t$ to its supplier and receives this order at the beginning of time period $t+\widetilde{l}_k+1$, where $\widetilde{l}_k$ is the order lead time at stage *k*. Excess demand is backlogged. We assume that the orders at any given stage become demands for the immediately upstream stage. Thus, we have $\widetilde{D}_{k+1,l}=\widetilde{Y}_{k,t}$. Let $\widetilde{q}_t$ represent the ordered quantity in period *t* to be delivered in period *t+l,* the timing of the event and the conservation of flow imply that:

$$\widetilde{q}_{k,t}=\widetilde{Y}_{k,t}-\widetilde{Y}_{k,t-1}+\widetilde{D}_t \tag{9}$$

It should be noted that all demands and lead times are considered to be uncertain and are represented by fuzzy triangular numbers.

To investigate how bullwhip effect occurs in this fuzzy environment, three key components need to be specified:

i. The end customer's demand process;
ii. The policy that the participant at each stage applies to determine its inventory level and order quantity;

iii. Forecasting method of each stage to forecast the demand and order to the upstream stage.

For the first component mentioned above, we allow the demand process for the generation of the mid-point of a triangular fuzzy number to be an *ARIMA(p, d, q)* process and the left and right points are generated randomly around the mid-point. For the second component, a fuzzified version of Hayman and Sobel (1984) policy is implemented. They showed that when end customer's demand is an *ARIMA* process, such a policy minimizes the total expected holding and shortage costs over an infinite horizon. Finally for the third component, a modified version of (Hong 2005) is applied to forecast the customer demand of each stage.

We assume that each participant of the supply chain applies the same inventory and order policy as follows:

$$\widetilde{D}_{k+1,t} = \widetilde{D}_{k,t} + (\widetilde{S}_{k,t} - \widetilde{S}_{k,t-1}) \tag{10}$$

where, $\widetilde{S}_{k,t}$ is the fuzzy value of "the order-up-to level" at stage k and period t. Here, $\widetilde{S}_{k,t}$ can be expressed as follows:

$$\widetilde{S}_{k,t} = \widetilde{m}_{k,t} + z_k \sqrt{v_{k,t}} \tag{11}$$

where,

$$\widetilde{m}_{k,t} = E\left(\sum_{i=1}^{\widetilde{l}_k+1} \widetilde{D}_{k,t+i} \mid \widetilde{D}_{k,t}\right) \tag{12}$$

$$v_{k,t} = \operatorname{var}\left(\sum_{i=1}^{\widetilde{l}_k+1} \widetilde{D}_{k,t+i} \mid \widetilde{D}_{k,t}\right) \tag{13}$$

$$z_k = \phi^{-1}(h_k /(p_k + h_k)) \tag{14}$$

In this case, all demands are considered to be fuzzy sets. The fuzzy number $\left(\sum_{i=1}^{\widetilde{l}_k+1} \widetilde{D}k,t+i \setminus \widetilde{D}k,t\right)$ can be extracted by using extension principle and forecasting of fuzzy demand from time to time $t+\widetilde{l}_k+1$, according to known demand at time t. Therefore, $E\left(\sum_{i=1}^{\widetilde{l}_k+1} \widetilde{D}k,t+i \setminus \widetilde{D}k,t\right)$ and var $\left(\sum_{i=1}^{\widetilde{l}_k+1} \widetilde{D}k,t+i \setminus \widetilde{D}k,t\right)$ are equal to variance and mean of a fuzzy number proposed in (Carlsson and Fuller 2001b) which is stated as follows:

$$E(A) = \int_0^1 \alpha\,(u^-(\alpha) + u^+(\alpha))\,d\alpha \tag{15}$$

To calculate the mean of the fuzzy number u, they also defined possibilistic variance of afuzzy number as:

$$Var(A) = \frac{1}{2}\int_0^1 \alpha (u^-(\alpha) + u^+(\alpha))^2 \, d\alpha \tag{16}$$

where, α is the α *-cut* value and $u^-(\alpha)$, $u^+(\alpha)$ are values in the left and right hand sides of the mid-point where their membership functions are equal to α. These formulas are used to calculate the following equations:

$$A1 +_w A2 = (m1 + m2, \max\{L1, R2\}, \max\{R1, L2\}) \tag{17}$$

$$A1 -_w A2 = (m1 - m2, \max\{L1, R2\}, \max\{R1, L2\}) \tag{18}$$

where, $Ai = (mi, Li, Ri)$ is a fuzzy number, and $+_w$ and $-_w$ are indices for weakest sum and minus.

10.2 Fuzzy sample variance and mean

Bullwhip effect happens when variance of orders amplify from downstream to upstream. Therefore, the variance of orders must be computed in each stage when one encounters fuzzy orders. For this reason, a fuzzy variance approach has to be chosen.

Expected value of a fuzzy random variable was introduced by Puri & Ralescu (1986). However, there is much less effort to define the variance or covariance of fuzzy random variable and study their properties. The variance and covariance of fuzzy random variable is of great importance in statistical analysis, linear theory of fuzzy stochastic and other fields of fuzzy stochastic theory and applications. The expected value of a fuzzy random variable defined in (Puri & Ralescu 1986) is a fuzzy number. However, it is proper that the variance and covariance of fuzzy random variables should have no fuzziness (Feng et al. 2001). As the case for real-valued random variables, the variance should be used to measure the spread or dispersion of the fuzzy random variables around its expected value. Here, we review the approach of Feng et al. (2001).

Define $E = \{u : R \to [0,1] | u \ satisfies (i) - (iii) below\}$, where u is normal and fuzzy convex; and it is upper semi-continuous. For the α -level set of $u \in E$, $[u]^\alpha = \{x \in R \mid u(x) \geq \alpha\}$, where $0 < \alpha \leq 1$. Then, they defined $u^+(\alpha)$, $u^-(\alpha)$ as the upper and lower endpoints of $[u]^\alpha$. They define the operation $\langle \bullet, \bullet \rangle$ as $E \times E \to [-\infty, +\infty]$ by the following equation:

$$\langle u, v \rangle = \int_0^1 (u^-(\alpha) v^-(\alpha) + u^+(\alpha) v^+(\alpha)) \, d\alpha \tag{19}$$

Then, the following properties have been considered for this operation:

(i) $\langle u, v \rangle \geq 0$ and $\langle u, v \rangle = 0 \Leftrightarrow u = \hat{0}$,

(ii) $\langle u, v \rangle = \langle v, u \rangle$,

(iii) $\langle u + v, w \rangle = \langle u, w \rangle + \langle v, w \rangle$,

(iv) $\langle \lambda u , v \rangle = \lambda \langle u , v \rangle$, (20)

(v) $| \langle u , v \rangle | \leq \sqrt{\langle u , u \rangle \langle v , v \rangle}$

where, u, v,w∈E and λ ∈[0, ∞).

For u, v∈E , if $\langle u , u \rangle < \infty$ and $\langle v , v \rangle < \infty$ from the property (v) in (20) they defined d* metric in $\{u \in E \mid \langle u, u \rangle < \infty\}$ as follows:

$$d_*(u, v) = \sqrt{\langle u, u \rangle - 2\langle u, v \rangle + \langle v, v \rangle} \tag{21}$$

Then, by these definitions, for a simple random independent and identically distributed sample X1,X2 ,...,Xn taken from fuzzy random variable X, where it's mean and variance are u and $\sigma 2$, fuzzy sample mean and variance are defined as (Feng et al. (2001)):

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{22}$$

$$S^2 = \frac{1}{2(n-1)} \sum_{i=1}^{n} d_*^2(X_i, \overline{X}) \tag{23}$$

10.3 Experiment

To experiment a typical bullwhip effect for a four stage supply chain system, we have used an *ARIMA*(1, 0, 1) for end customer's demand process. The other parameters of the model are as follows:

$\varphi_{1,1} = 0.5, \theta_{1,1} = 0.1, \quad \sigma = 50$ and $\tilde{l}_1 = \tilde{l}_2 = \tilde{l}_3 = \tilde{l}_4 = \tilde{1}$, where, $\tilde{1} = Triangular(0,1,2)$.

At first, as described before, end customer's demand is generated by using an ARIMA process, and then these values are fuzzified into some symmetric triangular fuzzy numbers. These fuzzy values are considered as demands. The proposed approach is used for forecasting purposes. Since any lead time also has a fuzzy value, when computing the value of $\widetilde{m}_{k,t}$ by using extension principle and cutting the $\tilde{l}_t$ in α level, the value of $m_{k,t}$ becomes a type-II fuzzy set. To overcome this problem, by using the centroid method, a defuzzification on the values of ($\sum_{i=1}^{\tilde{l}_k+1} \widetilde{D}k, t+i \setminus \widetilde{D}k, t$) is implemented,. The occurrence of the bullwhip is shown in Figure 3.

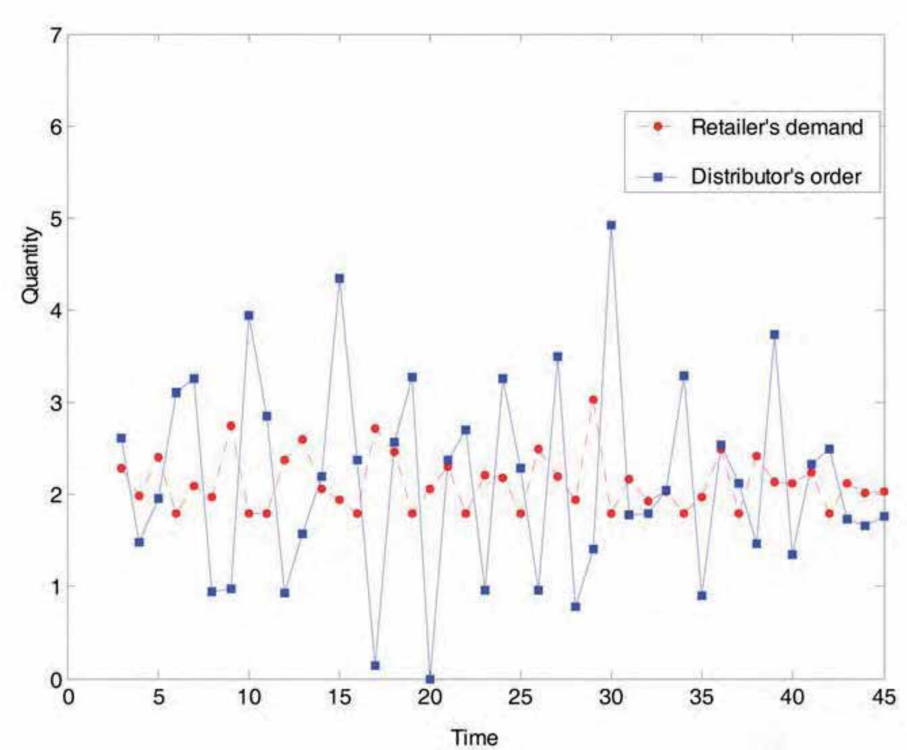

Figure 3. Retailer's demand and distributor's order in each period.

It is clear that the variance of demand is amplified in supply chain when demand is transferred from downstream to upstream stages. In order to compare the magnitude of information transformation, we need to use some metric. The simplest metric is comparing the sample variance, but it has some difficulties. If the bullwhip effects are indicated by simulation experiments at a wholesaler and a distributor, it can be expressed as $V(D_{retailer}) < V(D_{wholesaler}) < V(D_{distributor})$. At the same time, simulation experiments also indicate that the bullwhip effect at distributor is very weak compared with that at wholesaler, which implies that the degree of magnification is decreasing when moving up-stream. To quantify this, the metric of (Li et al. 2005) is applied. This metric is based on the relative comparison of the variance of sample points and is expressed as:

$$A_{i,j} = \frac{Var(D_i) - Var(D_j)}{Var(D_j)} \tag{24}$$

Therefore, when this metric is used, if $|A_{k+2,k+1}| > |A_{k+1,k}|$, it is said that theinformation transformation propagates from stage k to $k+2$ in an increasing magnitude.Otherwise, if $|A_{k+2,k+1}| < |A_{k+1,k}|$, we say that information transformation propagatesfrom stage k to $k+2$ in a decreasing magnitude. To compute

$Var(D_i)$, the formulas of samplevariance and mean of fuzzy numbers have been used. The results are shown in Table 1.

Variance of demand	Retailer	Distributor	Producer	Supplier
	0.0640	0.2994	1.0329	1.9142
Metric Value	-	0.7862	0.7721	0.4604

Table 1. Value of sample variance and BW metric for different stages

11. An agent-based model for reduction of bullwhip effect in supply chains

In general, global optimization is the central issue of system modeling approaches. The main interest of managers is to ensure that the overall cost is reduced and operations among various systems are integrated through coordination. Literature shows that reducing overall system cost and understanding how these savings are deployed among the supply chains (SC) entities are of the best interest. When the system is not coordinated, i.e., each entity in the supply chain does what is best for that entity, it results in local optimization. Each supply chain entity optimizes its own operation without considering the impact on other entities which often results in larger variation of inventory and demand in the entire SC. To have good coordination, managers need to communicate in detail, which is often a timeconsuming process. In addition, ineffective communication affects material flows and creates long lead times. One of the great disadvantages of separated decision making in supply chain which is a result of also rational human behavior is bullwhip effect (Liang & Huang 2005).

The observed performance of human beings managing supply chains, whether in field or laboratory settings, is usually from an optimal system-wide point of view. This may be due to the lack of incentives for information sharing, bounded rationality, or possibly the consequent of individual rational behavior that works against the interest of the group (Kimbrough et al. 2002).

Many information technologies have been developed for handling transactions in supply chains such as electronic document interchange (EDI) and enterprise resource planning (ERP). Lately, Internet-based technologies such as the ebXML and Web Service (Walsh 2002) have been emerging. However, despite the merits of these technologies, there exist some limitations in the flexibility and dynamic coordination of distributed participants in supply chains. The agent-based systems are alternative technologies for supply chain management because of certain features such as distributed collaboration, autonomy, and intelligence (Fox et al. 2000; Nissen 2000; Swaminathan 1997).

One of the main benefits of using agent-based technologies for supply chain management is the dynamic formation of supply chains using negotiations or contracts by agents (Walsh & Wellman 1999; Chen et al. 1999).

Agent technology has many desirable features such as autonomy, intelligence and collaboration for supply chain management. This is because the following key characteristics of supply chain management are well supported by the features of agent technology. First, there are multiple companies such as manufacturers, distributors, wholesalers, and retailers in supply chains. Second, companies in supply chains are independent firms and there is no single authority that governs the whole chain collaboration. They exchange information such as customer demands, inventory levels, and exceptional events, but do not control each

other one-sidedly. Third, intelligent coordination is required for planning and scheduling of production and logistics in a dynamic market situation.
This section presents an agent-based system with fuzzy methodology for reduction of bullwhip effects in supply chains. Here, a multi-agent based approach is presented to control the ordering quantity for every echelon and to find the minimal total cost of the entire supply chain and to reduce its related bullwhip effect. The main purpose of such a system is to coordinate all entities of the SC and to minimize the total cost. Each echelon has the same agent structure. In this research, two types of agents are employed: middle agent and software agent. Middle agents have the ability to collect the required data for software agent. The software agent by using a simulation module and a GA mechanism produces the best policy for the entire system.

11.1 Middle agent

Middle agents (are also called intermediate agents) in agent systems are internal agents which play a particular role, providing intermediate services. They are found under various names, e.g., brokers, controllers, facilitators, mediators, or matchmakers. Their role may range from that of providing yellow pages to dealing with intricacies of high level protocols for matching a request to a particular service (Shen et al. 2001).
In our proposed model, middle agents have a liaison role between manager of each echelon and the system. The middle agent exchange information about the demand quantity, lead times, inventory level and shortage level to the system. It also enables the demand agent to recalculate the cost and determine the ordering quantity whenever demand is changed.

11.2 Software agent

Intelligent software agents are defined as being a software program that can perform specific tasks for a user and possesses a degree of intelligent that permits it to perform parts of its tasks autonomously and to interact with its environment in a useful manner. In the proposed model, after being contacted by the middle agent, the software agent, by using a simulation module and a GA mechanism, determines the best ordering policy to minimize the total system cost and delivers the message back to each middle agent. In GA mechanism some fuzzy rules for ordering is generated and then by using simulation module the effect of such a rule on the whole system is calculated. The architecture of the proposed agentbased model is shown in Figure 4.
***Rules generation*:** The middle agent collects information including current on-hand inventory levels, shortage levels, lead time and customer demands, outstanding order and passes them to the software agent. Then, GA mechanism generates a number of rules and selects the best rules based on the results of the simulation procedure. After doing this process for some generations, the best rule is selected and the amount of order quantity is determined. The rest of this section presents a detailed description of the applied GA.
***Cost Function*:** The simulation module evaluates the cost of applying each rule by the following cost function. In our model all entities incur both inventory holding costs as well as penalty for shortage cost. Total cost of the system after M weeks is:

$$\tilde{TC} = \sum_{i=1}^{N} \sum_{j=1}^{M} \tilde{c}_{ij} \tag{25}$$

where, N is number of entities, $\widetilde{c}_{ij}$ cost of the j_{th} week for player i. and

$$\widetilde{c}_{ij} = \begin{cases} \widetilde{I}_i * h_i & \widetilde{I}_i > 0 \\ \widetilde{I}_i * p_i & \widetilde{I}_i < 0 \end{cases} \tag{26}$$

where, hi is the holding cost of entity i, pi is the shortage cost of retailer, and $\widetilde{I}_i$ is inventory level of the i_{th} entity. $\widetilde{I}_i = \widetilde{IL}_i + \widetilde{S}_i - \widetilde{D}_i$ in which $\widetilde{IL}_i$ is on-hand inventory of entity i at the beginning of each week. $\widetilde{S}_i$ is new shipment that player i received in the current time and $\widetilde{D}_i$ is the demand received from the downstream entity. Here, since all demands and lead times have fuzzy value, relations related to fuzzy arithmetic should be applied. For the defuzzification purpose, a *Mean of Maximum* method is used.

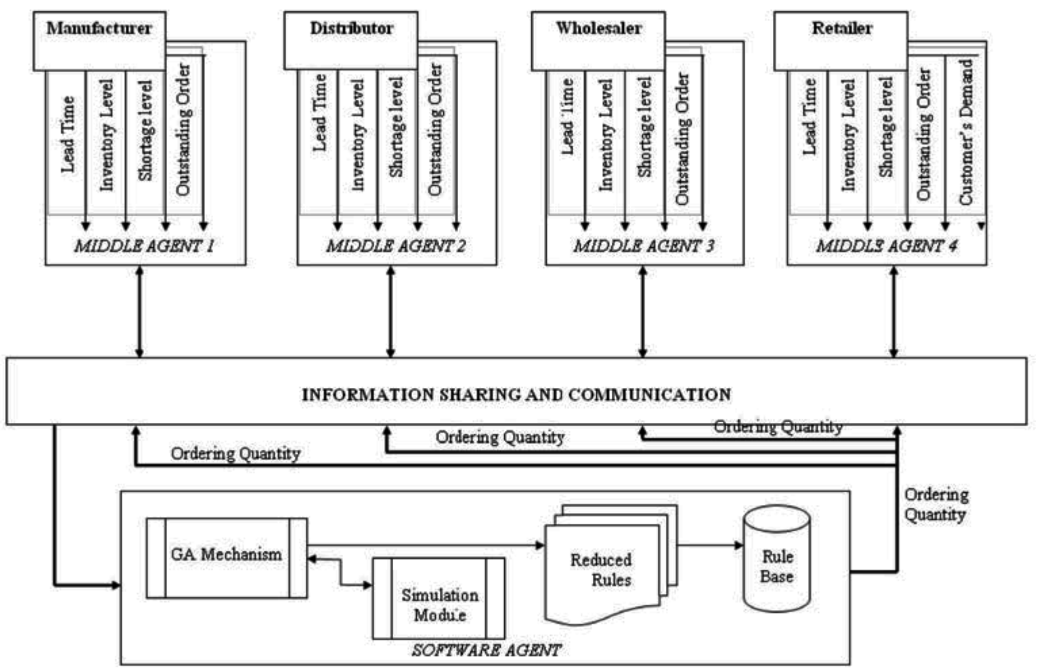

Figure 4. Agent Architecture of the proposed approach

Rule Representation: As mentioned earlier, customer demands are considered to be triangular fuzzy numbers. Each triangular fuzzy number can be determined by three parameters. In our agent-based model, each agent's rule is represented by three 5-bit binary strings. Each 5-bit binary string stands for one of the parameters for triangular fuzzy number. For example if the rule for retailer is "00101 00110 01001", it can be interpreted as $\widetilde{X}$ + (5, 6, 9). That is if demand is $\widetilde{X}$, then ordering quantity of retailer to the wholesaler is a triangular fuzzy number with parameters (5, 6,9) . In such cases, the main problem is that, when all agents are allowed to make their own decisions, the size of search space enlarges exponentially. The size of the search space for the above mentioned SC is 260 which is a very vast search space.

Each rule can be represented as a chromosome. In each generation, the values in each chromosome are sorted in a descending order, and then the first 4 biggest numbers in each chromosome are assigned to the upper bound of triangular fuzzy numbers, the second 4 ones are assigned to middle points, and the third 4 values are assigned to the lower bounds of fuzzy numbers. The population size in the developed algorithm incorporates 30 individuals.

***Initial Population Generation*:** We use the complete random method to generate initial population.

Fitness Function: A commonly used transformation, which is applied in the developed algorithm, is that of proportional fitness assignment.

Crossover: We apply multi-point crossover in the developed algorithm.

Selection: A roulette wheel selection procedure has been applied for selection operator inthe algorithm.

Mutation: We applied a random selection of new values in the developed algorithm in the mutation procedure.

Reinsertion: To maintain the size of the original population, the new individuals have to be inserted into the old population. We have used a random reinsertion in the algorithm.

Termination Condition: In the proposed algorithm, termination condition considered to be 2000 generation.

11.3 Validation of the proposed solution approach

To validate the proposed solution approach, we used $\tilde{1}-\tilde{1}$ policy (order whatever is ordered from your customer) as a heuristic to benchmark. Also the results of simulation process which was presented in section 2, show the performance of the system when there is no information sharing among the entities, are compared with the results of agent-based system.

11.3.1 Benchmarking policy

Chen et al. (1999) shows that the bullwhip effect can be eliminated under the base stock installation policy. The assumptions are all divisions of the supply chain work as a team, demand is stochastic and information and physical lead times are fixed positive numbers and only retailer occurs shortage cost. Team concept means that a common goal to optimize the system-wide performance is shared by all entity mangers. In this case, it is optimal for each division to follow an installation base-stock policy. The installation stock at a division is its on-hand inventory minus backlogged orders from the downstream entity, plus its outstanding orders. The optimal decision rule for a division manger is to place orders so as to keep its installation stock at a constant level.

As a special case of Chen's result, Kimbrough et al. (2002) show that when facing deterministic demand with penalty cost for every player, the optimal order for every player is 1-1 policy, order whatever is ordered from your customer.

Because there is no optimal solution for the situation in which demand is fuzzy stochastic number and lead times are fuzzy deterministic or stochastic numbers when every entity incurs holding cost, we will apply $\tilde{1}-\tilde{1}$ ordering policy as a heuristic to benchmark the results of our agent-based model. Here, two scenarios are presented to evaluate the performance of our agent-based solution.

11.3.1.1 First scenario:

When the demands are stochastic fuzzy numbers and the lead times aredeterministic fuzzy numbers.

For the first round of our experiments, we implement agent-based model performance for a situation in which mid-points of fuzzy triangular demands are generated by a normal distribution function with mean 20 and variance 5. The left and right points are generated randomly around the mid-points. Lead times are considered to be fixed at $\tilde{2} = (1, 2, 3)$. In this situation, the aim of this experiment is to find out whether agents can discover an appropriate ordering policy or not. For comparison of the performance of agent-based model, the total cost of the system is compared with the simulation model and also $\tilde{1}-\tilde{1}$ policy.

The results show that agents are able to find a good policy that outperforms the $\tilde{1}-\tilde{1}$ policy. In this case, agents found $\tilde{X}$ + (2, 5, 7) as retailer's rule for ordering, $\tilde{X}$ + (1, 4, 5) as wholesaler's rule for ordering, $\tilde{X}$ + (0, 3, 3) as distributor's rule for ordering, and $\tilde{X}$ + (0, 2, 3) as Manufacturer's rule for ordering with a total cost of 17338 which is better than both $\tilde{1}-\tilde{1}$ policy and simulation procedure. This policy leads to no bullwhip effect in the system. The interesting point is that the results show that bullwhip effect is reduced considerably by this approach. Table 3 shows the amounts of variance for different entities of the supply chain. Table 2 and Fig. 5 show that the proposed approach, can reduce bullwhip effect considerably. Table 3 shows the amounts of variance for different entities of the supply chain.

	Demand	Retailer's orders	Wholesaler's orders	Distributor's orders	Manufacturer's orders
Variance of Sim. Results	2.5456	6.7034	13.0928	46.4865	53.6578
Variance of mid-point	4.2935	4.2935	4.2935	4.2935	4.2935
Fuzzy sample variance	2.5456	2.8991	2.9698	2.9901	3.2056
Metric Value	-	0.121934	0.023806	0.006789	0.067226

Table 2. Demand and order variances of different entities in SC.

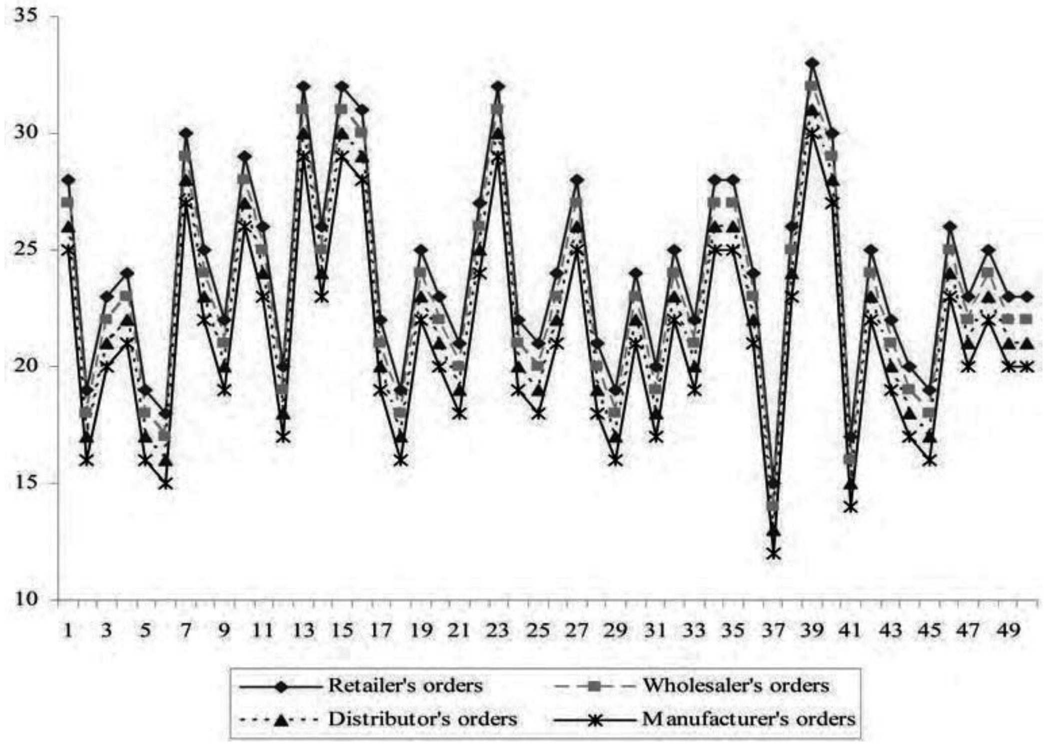

Figure 5. End customer's demand and ordering quantity of each stage

11.3.1.2 Second scenario:

When demand and lead times are both stochastic fuzzy numbers.

For the second scenario, we tested the agent performance in a situation that the lead times are also stochastic fuzzy numbers in addition to the stochastic fuzzy demands. We assumed that the lead time of each entity is a triangular fuzzy number in which the mid-point is generated by a normal distribution function with mean 3 and variance 1. The boundary points of the triangular fuzzy number are generated randomly around the mid-point. Demands are generated similar to the first example.

Results show that even in this situation agents are able to find policies which are better than $\widetilde{1}-\widetilde{1}$ policy. For this situation, agents found $\widetilde{X}+(1, 4, 8)$ as retailer's rule for ordering, $\widetilde{X}+(0, 4, 7)$ as wholesaler's rule for ordering, $\widetilde{X}+(0, 2, 5)$ as distributor's rule for ordering and $\widetilde{X}+(0, 2, 4)$ as Manufacturer's rule for ordering with a total cost of 58890.

Table 3 shows that in this situation, agents can find policies which reduce bullwhip effect in supply chain system considerably. This table also shows that variation of fuzzy sample variance in different stages is negligible, compared to the results of simulation model.

	Demand	Retailer's orders	Wholesaler's orders	Distributor's orders	Manufacturer's orders
Variance of Sim. Results	13.06694	26.30624	94.02763	108.4563	13.06694
Variance of mid-point	4.293517	4.293517	4.293517	4.293517	4.293517
Fuzzy sample variance	4.12258	4.3438	4.9081	5.6097	5.6386
Metric Value		0.050928	0.114973	0.125069	0.005125

Table 3. Demand and order variances of different entities in SC.

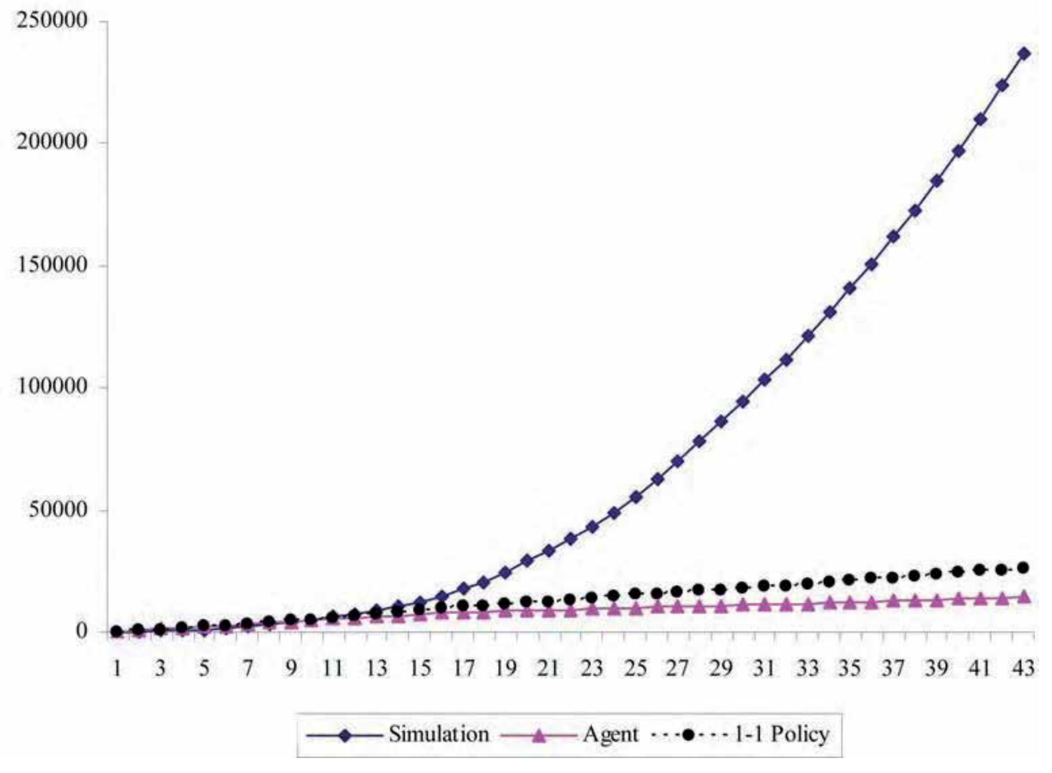

Figure 6. Cost comparison of Agent-Based model with simulation and 1-1 policy

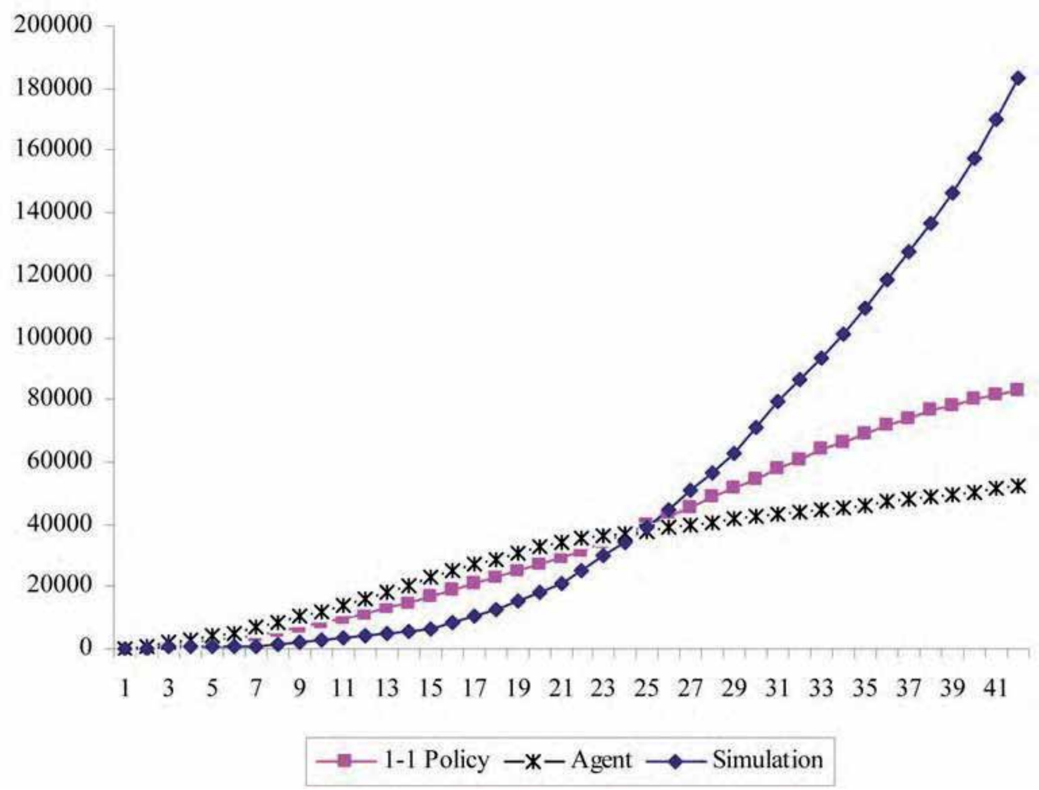

Figure 7. Cost comparison of Agent-Based model with simulation and 1-1 policy

12. Conclusions

This chapter proposes a proper modular architecture for the information agent, based on the inputs, functions, and outputs of the agent, for supply chain management. The proposed architecture has nine different modules, each of which is responsible for one or more function(s) for the information agent. Then, we explored the occurrence of bullwhip effect in supply chains, in a fuzzy environment. We built an agent-based system which can operate in a fuzzy environment and is capable of managing the supply chain in a completely uncertain environment. They are able to track demands, remove the bullwhip effect almost completely, and discover policies under complex scenarios, where analytical solutions are not available. Such an automated supply chain is adaptable to an ever-changing businessenvironment.

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12

Align Agile Drivers, Capabilities and Providers to Achieve Agility: a Fuzzy-Logic QFD Approach

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1. Introduction

At the beginning of the twenty-first century, the world faces profound changes in many aspects, especially marketing competition, technological innovations and customer demands. A world-wide dispersion of education and technology has led to intense and increasingly global competition and an accelerated rate of change in the marketplace and innovation. There is a continuing fragmentation of mass markets into niche markets, as customers become more demanding with their increasing expectations. This critical situation has led to major revisions in business priorities, strategic vision, and the viability of conventional and even relatively contemporary models and methods developed thus far [1]. To cope with these changing competitive markets, as well as the ability to meet customer demands for increasingly shorter delivery times, and to ensure that the supply can be synchronized to meet the peaks and troughs of the demand are obviously of critical importance [2, 3]. Hence, companies now require a high level of maneuverability encompassing the entire spectrum of activities within an organization. Consequently, agility in addressing new ways to manage enterprises for quick and effective reaction to changing markets, driven by customer-designed products and services, has become the dominant vehicle for competition [4].

Generally, agility benefits can mass customization, increase market share, satisfy customer requirements, facilitate rapid introduction of new products, eliminate non-value-added activities, reduce product costs and increase the competitiveness of enterprises. Accordingly, agility has been advocated as the business paradigm of the 21st century, being considered the winning strategy for becoming a global leader in an increasingly competitive market of quickly changing customer requirements [5-7]. However, the ability to build agility has not developed as rapidly as anticipated, because the development of technology to manage an agile enterprise is still in progress [4, 6, 8]. Thus, in embracing agility, many important questions must be asked, such as: Precisely what is agility, and how can it be measured? How will companies know when they possess this attribute since no simple metrics or indices are available? How and to what degree do the attributes of an enterprise affect its business performance? How does one compare agility with a competitive enterprise? To improve entrepreneurial agility, how does one identify the principal unfavorable factors? How can one assist in more effectively achieving agility [8-10]? Answers to such questions are critical to practitioners and the theory of agile entrepreneurial design. Therefore, the purpose of this research is to seek solutions to some of these problems, with a particular focus on agile strategic planning and measurement, as well as identifying the principal obstacles to improvement of agility.

Actually, the purpose of agile strategic planning is to unite the resources of an enterprise and to create business value. Agile enterprises are concerned with change, uncertainty and unpredictability within their business environment and making an appropriate response; therefore, these enterprises require a number of distinguishing attributes to promptly deal with the changes within their environment. Such attributes consist of four principal elements [7, 8]: responsiveness, competency, flexibility/adaptability and quickness/speed. Furthermore, the foundation for agility is comprised of the integration of information technologies, personnel, business process organization, innovation and facilities into strategic competitive attributes. To be truly agile, an enterprise must logically integrate and deploy a number of distinguishing providers with drivers and good capabilities, being finally transformed into strategic competitive edges [11].

Many theoretical models have been proposed for agile enterprise planning [1, 12-15]; however, only a few provide integrated methodologies suitable for adoption to enhance by identifying providers, beginning with the competitive bases of the enterprise. The relationship matrix in the quality function deployment (QFD) method provides an excellent tool for aligning important concepts and linking processes. Moreover, fuzzy logic is a useful tool for capturing the ambiguity and multiplicity of meanings of the linguistic judgments required to express both relationships and rates of agility attributes.To assist managers in more efficiently achieving agility, a systematic methodology, based on fuzzy logic and the relationship matrix in the QFD is devised to provide a means for linking the perspectives from agility drivers with their corresponding capabilities and providers, thereby measuring the agility of an enterprise as well as identifying the principal obstacles to improvement.

The remainder of this report is organized as follows. In Section II the related research is reviewed. In section III a conceptual model of an agile enterprise is described in detail for the development of a systematic evaluative methodology in Section IV. The development of a practical case is presented illustrated in Section V. Finally, Section VI a concluding discussion.

2. Review of related research

A. Methodology

Numerous studies for developing methodologies have been proposed to assist managers in the implementation of strategic planning for achieving agility. For example, to promote a new understanding of cooperation as a vital means of survival and prosperity in the new business era, Preiss et al. [12] proffered a generic model for approaching agility. This model consists of certain steps that can assist an enterprise in understanding its business environment and the changes occurring there, the attributes enabling the infrastructure, and the business processes that should be recognized in the subsequent actions of the organization to sustain its competitive advantage. The first integrated framework to achieve agility was proposed by Gunasekaran [15]. The framework explains how the major capabilities of agile manufacturing should be supported and integrated with appropriate providers to develop an adaptable organization. Seeking to exploit the concept and practices of agility, two research teams [1, 10] have developed a three-step methodology for achieving agility. This methodology provides manufacturing companies with a tool for understanding the total concept of agility, assessing their current positions, determining their need for agility and the capabilities required for achievement, as well as adopting relevant practices which can induce these capabilities. A three-step model was also suggested by Jackson and Johansson [14] to analyze the agility of production systems. Their methodology begins with an assessment of the degree of market turbulence, to determine the relevance of agility in a specific context. Then, the strategic view of the company is examined, with a particular focus on potentials to enhance flexibility and change competencies as viable strategies to achieve a competitive advantage.

Although structured frameworks to formulate agility have been identified, most of them for strategic formulation are structural in nature. Thus, to assure that the providers can satisfy the strategic direction of an enterprise, an integrated methodology suitable for adoption to enhance agility by identifying its providers, beginning with competitive bases of the enterprise, is critical to both practitioners and the theory of agile enterprise design.

B. Measurement

Many approaches to the measurement of agility have been proposed to assist managers in assessment; however, most of these methods assess only the capabilities of agility. Some authors [10, 16, 17] have defined an agility index as a combination of measurement of the intensity levels of enabling attributes; whereas, other measuring methods [18,19] have been developed on the basis of the logical concept of an analytical hierarchical process (AHP). An evaluation index for a mass-customization product manufacturing agility was devised by Yang and Li [20]. Furthermore, to overcome the vagueness of agility assessment, Tsourveloudis and Valavanis [21] designed some IF-THEN rules based on fuzzy logic; moreover, Lin et al. [6] developed a fuzzy agility index (FAI) based on providers using fuzzy logic. Each of these techniques, however, with the exception of the agility providers, seems to address only a limited aspect of a very complicated problem. Although each technique contributes to an understanding of the problem, each - functioning alone - is insufficient for handling the problem in its entirety because the selection of the provider and the assessment should be linked with the drivers and the capabilities [22]. It is therefore necessary to examine the problem from a broader perspective.

C. QFD Relationship Matrix

The QFD method was designed to emphasize detailed pre-planning to meet customer needs and requirements for new product development. It employs several charts, called house of quality (HOQ), to translate the desires of the customer into the design or engineering characteristics of the product and subsequently into the characteristics of the parts, process plan and production requirements related to its manufacture. Phase I translates the voice of the customer into corresponding engineering characteristics; phase II moves one step backward in the design process by translating the engineering characteristics into characteristics of the parts; phase III identifies the critical process parameters and operations; and finally, phase IV identifies the detailed production requirements. The basic format of the HOQ consists of seven different major components: (1) customer requirements (CRs), (2) importance of customers' requirements, (3) design requirements (DRs), (4) relationship matrix for CRs and DRs, (5) correlation among DRs (6) competitive analysis of competitors, and (7) prioritization of design requirements, as shown in Figure 1.

Although QFD has been proposed for customer-driven product development and delivery methodology, an enterprise can achieve various corporate strategic goals such as a reduction in customer complaints, improvement in design reliability and customer satisfaction, easier design change, a reduction in product-development-cycle time, and organizational efficiency by using this method [23, 24]. Similarly, QFD can be extended for aligning drivers with providers to achieve agility and make priority decisions concerning the specific provider improvements that should be made for enhancing the agility level of an enterprise.

A simplified form of the HOQ matrix, in which the importance of customers' requirements, correlation analyses among DRs are removed, is utilized in this study. This simplified form is called a relationship matrix, wherein CRs are represented on the left side. Identifying the relative importance of the various CRs is an important step in discerning those that are critical and also helps in prioritizing the design effort. DRs are represented on the upper portion of the relationship matrix. The relative importance of the DRs can be calculated by using the relative importance of the CRs and the level assigned to the relationships between CRs and DRs, presented in the main body of the matrix, which can be represented in symbolic or numerical form. The level of the relationships is typically assessed by an evaluation team in a subjective manner.

D. Fuzzy Logic

A fuzzy set can be defined mathematically by assigning a value to each possible member in a universe representing its grade of membership. Membership in the fuzzy set, to a greater or lesser degree, is indicated by a larger or smaller membership grade. Fuzzy-set methods allow uncertain and imprecise systems of the real world to be captured through the use of linguistic terms so that computers can emulate human thought processes. Thus, fuzzy logic is a very powerful tool capable of dealing with decisions involving complex, ambiguous and vague phenomena that can be assessed only by linguistic values rather than by numerical terms. Fuzzy logic enables one to effectively and efficiently quantify imprecise information, perform reasoning processes and make decisions based on vague and incomplete data [25]. On the basis of previous study [26], the experts can make a significant measurement of the possibility of an event when it is known; however, in uncertain situations characterized by either a lack of evidence or the inability of the experts to make a significant measurement when available information is scarce, managers often react very incompetently. Fuzzy logic, by making no global assumptions about the independence, exhaustiveness, or exclusiveness of the underlying evidence, tolerates a blurred boundary in definitions [25]. Thus, fuzzy logic brings the hope of incorporating qualitative factors into decision-making.

Fuzzy logic is currently being used extensively in many industrial applications as well as in managerial decision making. For example, it has been used in multi-attribute decision-making situations to select R&D project evaluation [27]. Ben Ghalia et al. [28] used fuzzy-logic inference for estimating hotel-room demand by eliciting knowledge from hotel managers and building fuzzy IF-THEN rules. Lin and Chen [29] devised a fuzzy-possible-success-rating for evaluating go/no-go decisions for new-product screening based on the product-marketing competitive advantages, superiority, technological suitability and risk. Chen and Chiou [30] devised a fuzzy credit rating for commercial loans. Hui et al. [31] obtained data from experienced supervisors to create a fuzzy-rule-based system for balance control of assembly lines in apparel manufacturing. Organizational transformations have been widely adopted by firms to improve competitive advantage. Chu et al. [32] uses a nonadditive fuzzy integral to develop a framework to assess performance of organization transformation.

3. Conceptual model of agile enterprise

The goal of an agile enterprise is to enrich/satisfy customers and employees. An enterprise essentially possesses a set of capabilities for making appropriate responses to changes occurring in its business environment. However, the business conditions in which many companies find themselves are characterized by volatile and unpredictable demand; thus, there is an increasing urgency for pursuing agility. Agility might, therefore, be defined as the capability of an enterprise to respond rapidly to changes in the market and customers' demands. To be truly agile, an enterprise should possess a number of distinguishing agility-providers. From a review of the relevant literature [1, 4, 6, 12, 14], the author has developed a conceptual model of an agile enterprise, as shown in Figure 2.

The main driving force behind agility is change. There is nothing new about change; however, change is currently occurring at a much faster rate than ever before. Turbulence and uncertainty in the business environment have become the main causes of failures in enterprises. The number of changes and their type, specification or characteristics cannot be easily determined and probably is indefinite. Different enterprises with dissimilar characteristics and circumstances experience various changes that are specific and perhaps unique to themselves. However, there are some common characteristics in changes that occur, which can produce a general consequence for all enterprises. By summarizing previous studies [1, 4, 7, 8], the general areas of change in a business environment can be categorized as (1) market volatility caused by growth of the market niche, increasing introduction of new product and shrinkage of product life; (2) intense competition caused by rapidly changing markets, pressure from increasing costs, international competitiveness, Internet usage and a short development time for new products; (3) changes in customer requirements caused by demands for customization, increased expectations for quality and quicker delivery time; (4) accelerating technological changes caused by the introduction of new and efficient production facilities and system integration; and (5) changes in social factors caused by environmental protection, workforce/workplace expectations and legal pressure.

Agile enterprises are concerned with change, uncertainty and unpredictability within their business environment and making appropriate responses. Therefore, such enterprises require a number of distinguishing capabilities, or "fitness," to deal with these concerns. These capabilities consist of four principal elements [7, 8]: (1) responsiveness, the ability to see/identify changes, to respond quickly, reactively or proactively, and to recover; (2) competency, the efficiency and effectiveness of an enterprise in reaching its goals; (3) flexibility/adaptability, the ability to implement different processes and achieve different goals with the same facilities; and (4) quickness/speed, the ability to culminate an activity in the shortest possible time.

Achieving agility requires responsiveness in strategies, technologies, personnel, business processes and facilities. Agility-providers should exhibit agile characteristics as well as make available and determine the agility capabilities and behavior of an enterprise. Numerous studies dedicated to identifying agility-providers from which organization leaders can select items appropriate to their own strategies, organizational business processes and information systems have been conducted. For example, Kumar and Motwani [33] identified twenty-three factors that influence a firm's agility. Goldman et al. [34] suggested that agility has four underlying components: (1) delivering value to customers, (2) being ready for change, (3) valuing human knowledge and skills, and (4) forming virtual partnerships. The "next generation manufacturing" project identified six attributes for agility: (1) customers, (2) physical plant and equipment, (3) human resources, (4) global markets, (5) core competency, and (6) practices and cultures [35]. Moreover, Yusuf et al. [36] proffered a set of thirty-two agile attributes grouped into four dimensions: (1) core competency management, (2) virtual enterprise, (3) capability for reconfiguration, and (4) knowledge-driven enterprises. These attributes, representing most aspects of agility, determine the entire behavior of an enterprise. Most recently, Ren et al. [37], following the work of Yusuf et al. [36] based on a survey circulated among UK enterprises, conducted principal component analysis to confirm the correlations between the thirty-two attributes. Finally, six principal components encompassing fifteen attributes were identified as critical agility-enabling-attributes: (1) human knowledge and skills, (2) customization, (3) partnership and change, (4) technology, (5) integration and competence, and (6) team-building. From this review we can see that different researchers provide certain insights into different aspects of agility providers. It is highly probable that there is no single set of agility providers reflecting all aspects.

Although several researchers [1, 12-15] have accepted a conceptual model for achieve agility, the purpose of agile strategic planning is to unite the resources of an enterprise to compete with the change in environment and to create business value, which according to some studies [4, 22] can be maximized and the competitive threat minimized only by selecting agile providers for investments aligned to the company's business strategy and competitive bases in the market. Thus, the first priority should be to understand the relationships among the specific market field requirement, as well as the agility capabilities and providers, to deploy and integrate both capabilities and providers, and to transform them into a competitive edge.

To assist managers in more efficiently achieving agility, on the basis of the conceptual model of an agile enterprise, and by using the relationship matrix in the QFD approach, a systematic model for linking and integrating agility drivers, capabilities and providers, can be constructed as shown in Figure 3. Specifically, this model can be described as follows:

- Analysis of agile strategy: to identify the degree of the agile abilities that can provide the required strength for responding to changes and searching for competitive advantage by maintaining alignment between agility drivers and agile abilities.
- Identification of agile providers: to find agility providers constituting the means by which the so-called needs of an enterprise relation to capabilities can be achieved by linking between abilities and providers.

4. A fuzzy QFD-based algorithm for evaluation of agility

As mentioned in the previous section, the deployment and integration of agility drivers, capabilities and providers, and their transformation into a competitive edge is critical for achieving agility. Due to an either "imprecise" or "vague" definition of agile attributes and relationships, the deploying and integrating evaluation process is associated with uncertainty and complexity. Managers must make a decision by considering agile attributes and relationships which might have non-numerical values. All attributes must be integrated within the evaluation decision although none of them may exactly satisfy the ideals of the enterprises. Conventional "crisp" evaluation approaches cannot handle such decisions suitably or effectively. Since humans have the capability of understanding and analyzing obscure or imprecise events which are not easily incorporated into existing analytical methods, the corporate strategic planning decision is made primarily on the basis of the opinions of experts. On the basis of previous research [38], in situations where evaluators are unable to make a significant assessment, linguistic expressions are used to estimate ambiguous events. Linguistic terms usually have vague meanings. One way to capture the meanings of linguistic terms is to use the fuzzy-logic approach to associate each term with a possibility distribution [39].

To assist managers in more efficiently achieving agility by using the relationship matrix in the QFD approach and fuzzy logic, an evaluation algorithm composed of four major parts (as shown in Figure 4) was devised for development and evaluation. First, identify the agility drivers on the basis of a survey of the business operation environment, determine the agility-level needs and identify the requirements for measuring the capabilities, and select the required providers for assessment. Second, apply the relationship matrix to link and analyze the fuzzy average relation-weight of the capabilities and providers. Third, synthesize the fuzzy ratings and average relation-weights of the capabilities to obtain the fuzzy-agility-index (FAI) of the enterprise and match the FAI with an appropriate linguistic term to label the agility level. Fourth, synthesize the fuzzy ratings and average relation-weights of the providers to obtain the fuzzy merit-relation-value index for each and rank them to identify the major barriers to enable managerial proactive implementation of appropriate ameliorating measures, a stepwise procedure for which follows.

1. Form a self-assessment committee.
2. Collect and survey data or information to identify the agility drivers, determine the needed capabilities and select the required providers for assessment.
3. Select the preference scale for measurement.
4. Apply the relationship matrix and use linguistic measurement to evaluate the agility attributes, relationship-levels and prepare a translation.
5. Analyze the fuzzy average relation-weights of the capabilities and providers.
6. Aggregate the fuzzy ratings and average relation-weights of capabilities into an FAI.
7. Match the FAI with an appropriate linguistic agility level.
8. Analyze the agility and offer suggestions.

A. Self-Assessment Committee

The essentials of an agile enterprise consist of integration of strategies, personnel, processes, networks and information systems. For knowledge acquisition to be successful, it is important that a variety of experts from different functions be chosen. Such a selection ensures that not only the complete domain is covered, but also that no single aspect of the business receives a greater emphasis within the final system.

B. Preparation for Assessment

Before assessing, the committee must survey the changes in the business operation environment and examine the organization's capability. On the basis of the external environmental survey and internal capability assessment, the committee can identify the main drivers, determine the level of agility needed and the capabilities of the enterprise in response to unpredictable changes, and select the agility-enabled attributes that are the means by which the so-called capabilities can be achieved.

C. Preference Scale System

Due to impreciseness and ambiguity in the criteria, which exist in the evaluation of agility, a precision-based evaluation may not be practical. Thus, the ratings of the attributes and the relationship-level assessment are frequently measured in linguistic terms rather than numerical ones.

The ad hoc usage of linguistic terms and corresponding membership functions is characteristic of fuzzy logic. It is notable that many popular linguistic terms and corresponding membership functions have been proposed for assessment [38, 40]. For the sake of convenience and in lieu of elicitation from the assessors, linguistic terms and corresponding membership functions were obtained directly from previous studies, or, on the basis of the needs of cognitive perspectives and available data characteristics, data from previous studies were used as the foundation for modification to meet individual situations and requirements, the results for which more satisfactorily fit users' needs. Furthermore, it is generally suggested that linguistic levels not exceed nine levels representing the limits of absolute human discrimination [41].

D. Relationship-Matrix Application, Linguistic Measurement, and Translation

In preparation for evaluating agility, the assessors must survey and study the related data or information concerning implementation to gain an understanding of what will be considered in the evaluation.

After studying the data, on the basis of the experts' experience and knowledge, the assessors can directly use the aforementioned linguistic terms to assess the rating which characterizes the merit level of the various factors. Furthermore, the linguistic terms can be used to assess interrelationship level located in the central portion of the relationship matrix, indicating the experts' perceptions regarding relationships between drivers, capabilities and providers, implemented by direct assignment or indirect pair comparisons.

After the factors are rated and the interrelationship-level evaluated, the fuzzy numbers such as those listed in Table I are used to approximate the linguistic values.

E. Analysis of Fuzzy Average Relation-Weights

Aggregation of the different experts' opinions in group decision-making is important, wherein many methods such as the arithmetical mean, median, and mode can be used. Since the median operation is more robust in a small sample, this method is recommended for aggregating these assessments.

On the basis of the traditional QFD methodology [42] and the definition of the fuzzy weighted average [43], the fuzzy average relation-weight representing the total relationship-levels between a particular column item and the entire list of row items can then be calculated as

$$FARWAC_J = \sum_{i=1}^{m}(FRLADAC_{ij} \otimes FLCAD_i) \Big/ \sum_{i=1}^{m} FLCAD_i \tag{1}$$

where $FARWAC_j$ denotes the fuzzy average relation-weight of the j^{th} agility capability to all the agility drivers; $FLCAD_i$ denotes the fuzzy level in change of the i^{th} drivers; $FRLADAC_{ij}$ denotes the fuzzy relationship-level between driver i and capability j.

$$FARWAP_k = \sum_{j=1}^{n}(FRLACAP_{jk} \otimes FARWAC_j) \Big/ \sum_{j=1}^{n} FARWAC_j \tag{2}$$

where $FARWAP_k$ denotes the fuzzy average relation-weight of k^{th} providers to all the agility capabilities; $FARWAC_j$ denotes the fuzzy average relation-weight of the j^{th} capability

derived from Eq (1); $FRLACAP_{jk}$ denotes the fuzzy relation-level between capability j and provider k.
The calculation of the membership function of a fuzzy weighted average is tedious, as indicated in [44, 45].

F. Aggregation of Fuzzy Ratings and Average Relation-Weights into Fuzzy-Agility Index

Representing the composite agility level of an enterprise, the fuzzy-agility index (*FAI*) constitutes a fusion of information, i.e., a consolidation of the fuzzy merit of agility capabilities with the fuzzy average relation-weight of the drivers. The higher the *FAI* of an enterprise is, the higher its agility.
According to the fuzzy weighted average operation [43], the *FAI* is defined as

$$FAI = \sum_{j=1}^{n} (FMAC_j \otimes FARWAC_J) \Big/ \sum_{i=1}^{m} FARWAC_J \tag{3}$$

where $FMAC_j$ denotes the fuzzy merit of the j^{th} agility capability and $FARWAC_j$ denotes the fuzzy average relation-weight of the j^{th} capability derived from Eq (1).

G. Matching FAI with an Appropriate Linguistic Level

Once the FAI has been compiled, one can further approximate a linguistic label whose meaning is the same as (or closest to) the meaning of the FAI from the natural-language expression set of an agility label (AL).
Several methods for matching the membership function with linguistic terms have been proposed. Three basic techniques include (1) Euclidean distance, (2) successive approximation, and (3) piecewise decomposition. The Euclidean distance method is most frequently utilized because it is the most intuitive form of human perception of proximity [46].
The Euclidean method consists of calculating the Euclidean distance from the given membership function to each functions representing the natural-language agility level expression set. Suppose that the natural-language agility level expression set is AL, U_{FAI} and U_{ALi} are the membership functions of FAI and the natural-language agility level expression, respectively. Then, the distance between the fuzzy number *FAI* and each fuzzy-number AL_i $\in$ AL can be calculated as

$$d(FAI, AL_i) = \left\{ \sum_{x \in p} \left(U_{FAI}(x) - U_{AL_i}(x) \right)^2 \right\}^{1/2} \tag{4}$$

where $p = \{x_0, x_1, \ldots, x_m\} \subset [0, 1]$ so that $0 = x_0 < x_1 < \ldots < x_m = 1.0$. To simplify, let p = {0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1}. Then, the distance from the *FAI* to each of the members in the set AL can be calculated and the closest natural expression with the minimum distance identified.

H. Analysis and Suggestions

As mentioned in the previous section, an evaluation of agility not only determines the agility of an enterprise but also, most importantly, helps managers identify the principal adverse factors for implementing an appropriate plan to enhance the agility level.
Agility-enabling attributes are supposed to provide and determine the entire agile behavior of an enterprise. To identify the principal obstacles to enhancing the agility level, a fuzzy agility-provider merit-relation-value index (*FAPMRVI*) combining the merit ratings and the

average relation-weights of providers derived from Eq (2) is defined. The lower the *FAPMRVI* of a factor is, the lower the degree of contribution for the factor.
If the fuzzy average relation-weight is used to calculate $FAPMRVI_k$ directly, the high value obtained neutralizes the low merit ratings in the calculation of *FAPMRVI*; therefore, the actual principal obstacles (low merit rating and high average relation-weight) cannot be identified. If a high value is given to $FARWAP_k$, then [(1, 1, 1) θ $FARWAP_k$] becomes a low value. Hence, to elicit the factor with the lowest merit rating and the highest average-relation-weight for each agility provider *k*, the fuzzy index for $FAPMRVI_k$ is defined as

$$\mathrm{FAPMRVI_k} = \mathrm{FMAP_k} \otimes \mathrm{FARVAP'_k} \tag{5}$$

where $FARVAP'_k$ = [(1, 1, 1) θ $FARWAP_k$]; $FMAP_k$ denotes the fuzzy merit of the k^{th} agility provider.
Since fuzzy numbers do not always yield a totally ordered set as real numbers do, all the $FAPMRVI_k$ must be ranked. Many methods have been developed to rank fuzzy numbers [40, 47]. Here, the ranking of the fuzzy numbers is based on Chen and Hwang's left-and-right fuzzy-ranking method [40] since it not only preserves the ranking order but also considers the absolute location of each fuzzy number. The shortcoming of this method is that the ranking score depends on the definition of their fuzzy maximizing and minimizing sets.
In the left-and-right fuzzy-ranking method, the fuzzy maximizing and minimizing sets are, respectively, defined as

$$U_{\max}(x) = \begin{cases} x, & 0 \le x \le 1 \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

$$U_{\min}(x) = \begin{cases} 1-x, & 0 \le x \le 1 \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

When a triangular fuzzy number is given, the *FAPMRVI* defined as $U_{FAPMRVI}\ R \rightarrow [0, 1]$ with a triangular membership function. Thu, the right-and-left scores of the *FAPMRVI* can be obtained, respectively, as

$$U_R(FAPMRVI) = \sup_x\left[U_{FAPMRVI}(x) \wedge U_{\max}(x)\right] \tag{8}$$

$$U_L(FAPMRVI) = \sup_x\left[U_{FAPMRVI}(x) \wedge U_{\min}(x)\right]. \tag{9}$$

Finally, the total score of the *FAPMRVI* can be obtained by combining the left and right scores, being defined as

$$U_T(FAPMRVI) = \left[U_R(FAPMRVI) + 1 - U_L(FAPMRVI)\right]/2\,. \tag{10}$$

5. A practical case study

In this section, an agility development project of an international IT products-and-services enterprise in Taiwan is cited to demonstrate the evaluation procedure for this approach.

A. Subject of Case Study

"Enterprise A" is an internationally recognized IT products-and-services company, particularly noted for PCs and notebooks, earning an annual revenue of about US $6.2 billion in 2005. This enterprise employs marketing and service operations across the Asia-Pacific Rim, Europe, the Middle East, and the Americas, supporting dealers and distributors in more than 100 nations. In the 1990's, the markets for IT products matured; moreover, low-cost production in developing nations grew, thus prompting large multinational firms to simultaneously provide local responsiveness and global integration to in reaction to an uncertain business environment. Such changes profoundly challenged the enterprise. To achieve and sustain global success and satisfy new small-niche markets, this enterprise strived to become a major global supplier to enrich its customers, reduce to-market time, reduce the total cost of ownership, and enhance overall competitiveness.

Since an enterprise has been advocated as the 21st-century operation paradigm, and being perceived as a winning strategy for becoming national and international leader, the corporate management team (executive team) concluded that it wished to achieve an extremely agile enterprise through continuous improvement processes. Thus, an assessment team led by the executive vice president was organized. This team was selected from the most knowledgeable personnel who had mastered the principles of an agile enterprise and whose job it was to investigate and correct problems. The team membership encompassed the vice president of marketing, the general auditor, the global manufacturing manager, the director of human resources, a senior project manager and two consultants for business strategy. Each member brought particular concerns and desires into the decision, which had to be reconciled by consensus, a necessary procedure since all parties would contribute to the success or failure of the project.

B. Commitments of Project

The aim of agility evaluation is to produce a good set of results, from which an agility index is determined for perceptions of the current situation, and another index for the goals toward increasing the agility of the enterprise. Since top-level commitment is essential, specific objectives for the development project were agreed on by the CEO:

- To implement an enterprise-wide self-assessment for establishing a baseline;
- To identify the strengths of the enterprise and areas needing improvement for feedback to the management team;
- To feed opportunities for improvement into the business planning cycle, including corporate objectives; and
- To develop the process of self-assessment by using the agile enterprise model as an annual component of the business cycle.

C. Evaluation by Fuzzy QFD-Based Algorithm

When enterprise A sets the goal to implement an agile enterprise, the committee had several questions, such as: Precisely what is agility, and how can it be measured? How can both analytical and intuitive understandings of agility be developed in a particular business environment? How can the agility of enterprise A be improved? Answering these questions requires knowledge of what to measure, how to measure it and how to evaluate the results. Moreover, how to integrate drivers, capabilities and providers into alignment must be taken into account if the enterprise is to implement agility. Although important concepts and steps for development formulation have previously been identified, there is still no systematic tool to integrate these concepts. Furthermore, due to the existing ill-defined and ambiguous elements concerning agility factors and their interrelationships, experts can easily differentiate between high, medium, and low; however, it is difficult to judge whether a value (e.g., 0.2) is low or another value (e.g., 0.3) is also low. Therefore, it is easier to use linguistic terms to measure ambiguous events. Since linguistic variables contain ambiguity and a multiplicity of meanings and the information obtained can be expressed as a range in a fuzzy set instead of a single value as in traditional methods, fuzzy logic may be applied in this evaluation context. On the basis of the procedures of the fuzzy QFD-based algorithm, the agility development evaluation was implemented and the goal achieved. The deliberations concerning how to initiate agility development are summarized below:

1) Identify agility drivers, determine capabilities and select providers for assessment. To accurately elicit assessment criteria reflecting the entire set of features of an agile enterprise within a period of ten days, the committee made a series of business-environment changes, as well as trend surveying and analysis, the major content of which included changes in the marketplace, competitive circumstances and criteria; technological innovations and applications; changes in customer requirements; and changes in social factors. Moreover, to facilitate the experts' holistic understanding of the current situation, two review meetings were held to discuss a series of activities, the major content of which included

- Enterprise characteristics: enterprise priorities (quality, cost, time, customers satisfaction, etc.), perceived quickness, responsiveness, core business and competencies, as well as specific enterprise problems;
- Policy and strategy: the key factors prompting the enterprise to change and the strategies adopted;
- Business structure: organization, process, personnel, information technology and innovative structures providing the capability for achieving agility;
- Practices: those performed in response to change

On the basis of discussion results, the committee further referred to the factors proposed in previous studies [1, 4, 7, 8, 10, 16-18]. The agility drivers were identified and the capabilities and providers for assessment selected, as shown in Table II. (This Table presents merely what the author assessed to be the most prevalent and meaningful factors for this case study).

2) Determine the preference scale for measurement. This is based on the needs for cognitive perspectives and available data characteristics and also considers the linguistic terms used in previous studies and modified to incorporate enterprise A situations. Furthermore, after two days of discussion based on a long-standing recognition of the meaning of linguistic values, ultimately the committee selected for assessment the linguistic terms and associated fuzzy numbers listed in Table I.

3) Apply the relationship matrix and use linguistic terms to assess agility attributes and relationship-levels, and translate the linguistic terms into fuzzy numbers. Within a period of six days, a series of brainstorming sessions was held to identify the relationships among the variables. For this, the experts were asked about the mutual relationships among variables (e.g., how a particular variable helps to achieve the others). By using the conclusions in the review meetings and brainstorming session, and on the basis of their experience, knowledge and judgment, the committee members applied the relationship matrix (as shown in Tables III and IV) and used the level scale W= {Extremely Low [EL], Very Low [VL], Low [L], Fair [F], High [H], Very High [VH], Extremely High [EH]} to measure the degree of change in the agility drivers. They used the value scale RS = {Very Low [VL], Low [L], Fair [F], High [H],

Very High [VH]} to evaluate extent of the relationships between agility drivers and capabilities, as well as the relationship-levels between capabilities and providers; moreover, they used the rating scale R = {Worst [W], Very Poor [VP], Poor [P], Fair [F], Good [G], Very Good [VG], Excellent [E]} to assess the merit ratings of the capabilities and providers. A sample of the linguistic assignment is shown in Tables III and IV. Furthermore, on the basis of the associated relations shown in Table I, fuzzy numbers approximating the linguistic terms and linguistic assignments were translated into fuzzy numbers.

4) Analyze the fuzzy average relation-weight in the relationship matrix. Before this analysis, the committee used the median operation to integrate the different assignments under the same factors given by different experts. Furthermore, by applying Eqs. (1)-(2), the fuzzy average relation-weights of the agility capabilities and providers can be calculated, respectively. The results are listed in Table V.

5) Aggregate the fuzzy ratings and fuzzy average relation-weights into an FAI. By applying Eq (3), the FAI for enterprise A was obtained as

$$FAI = (0.37, 0.56, 0.75).$$

6) Match the FAI with an appropriate linguistic level. Once the FAI was obtained, to identify the agility level, the committee further approximated a linguistic label whose meaning is the same as (or closest to) the meaning of the *FAI* from the natural-language agility-level (AL) expression set. In this case, the set AL = {Definitely Agile [DA], Extremely Agile [EA], Very Agile [VA], Highly Agile [HA], Agile [A], Slightly Agile [SA], Fairly [F], Slightly Slow [SS], Slowly [S]} was selected for labeling, the linguistics and corresponding membership functions of which are shown in Figure 5. Then, by using Eq (4), the Euclidean distance D from the *FAI* to each member in set AL was calculated:

$D(FAI, DA) = 2.0094$, $D(FAI, EA) = 2.0094$, $D(FAI, VA) = 1.7277$,
$D(FAI, \mathrm{H}A) = 0.9924$, $D(FAI, A) = 1.1405$, $D(FAI, \mathrm{SA}) = 1.8168$,
$D(FAI, F) = 2.0094$, $D(FAI, SS) = 2.0094$, $D(FAI, S) = 2.0094$

Thus, by matching a linguistic label with the minimum D, the agility level of enterprise A can be labeled as "Highly Agile", as shown in Figure 5.

7) Analyze and suggest. Since the agility index of enterprise A is "Highly Agile" (according to the evaluation), far from the "Extremely Agile" objective, obstacles within the organization can stop or impact the achievement of the company. Agility providers are supposed to enable and determine the entire agile behavior of an enterprise. By applying Eq (5), the fourteen fuzzy agility-provider merit-relation-value indexes (*FAPMRVIs)* listed in Table VI were obtained.

Moreover, by applying Eqs (6)-(10), the *FAPMRVIs* were defuzzified, as listed in Table V. These indices represent the effect of each provider contributing to the agility level of enterprise A. On the basis of the Pareto principle, the committee decided to focus their resources on a few critical factors and sets a scale of 0.2 as the management's threshold for identifying the factors for improvement. Subsequently, as shown in Table VI, four providers performed lower than the threshold, namely (1) first-time right design, (2) multi-skilled and flexible personnel, (3) response to changing market requirements, and (4) cross-functional teams. These providers represent the most significant contributions for enhancing the agility of the enterprise. In connection with the weakest providers within the organization, the committee suggested that an action plan be implemented to improve the adverse providers and to enhance the agility level of the company.

After five years and ten cycles of continuous implemented improvement, the agility index of enterprise A has risen close to the "Extremely Agile" level; moreover, the managers are able to capture information on demand immediately from all over the world to make rapid and appropriate decisions to respond more efficiently and effectively to customers. The tangible benefits are the mean lead-time for responding to customers' demands reduced by approximately 37% under the same inventory level; sales-average increased by 11%, 23%, 27%, 17% and 19% during the five years; an ascent from ninth of fourth position in the world market, especially boosted by becoming the leading brand of PCs and notebooks in the European market.

6. Discussion and conclusions

The agility of an enterprise is perceived as the dominant competitive vehicle. This report has highlighted the following questions: How close is the enterprise to becoming agile? How can the enterprise effectively improve its agility? Deploying and integrating agility providers, capabilities and drivers and transforming them into strategic competitive edges are critical for an enterprise to achieve agility. Although important concepts and steps for achieving agility have been identified, there is still no systematic tool for integrating these steps. Most of the existing approaches for agility development are structural in nature. Also, conventional (crisp) evaluation approaches which are unsuitable and ineffective for handling situations which by nature lead to complexity and vagueness have been evaluated. To compensate for these limitations, a QFD-based framework to logically integrate the agility provider, capability and driver has been proposed. The methodology provides a systematic structure for translating the agility drivers in the business environment into capabilities needed and subsequently for determining the requirements of agility-enabled attributes. In addition a fuzzy agility index (FAI) composed of agility capability ratings and its relation-weights with drivers has been developed for agility measurement in an enterprise. This report has also described how the proposed approach was applied to develop agility in a Taiwanese PC enterprise. Through development and evaluation, it has been shown that the proposed framework and procedures can enhance the agility of an enterprise, as well as ensure a competitive edge.

This method has been developed from the QFD concept and adapted for a PC enterprise which served as an initial case study for validating the model and approach. The enterprise and managers involved in the case study were generally pleased with the approach. This work provides potential value to practitioners by offering a rational structure to logically integrate different elements at various stages of strategic planning. The uncertainty and vagueness of assessment of each attribute and relationship have been addressed to assure relatively realistic information. An unprecedented application of the QFD and fuzzy logic has been demonstrated to researchers.

Since the case study has demonstrated the usefulness of the model for business strategic planning, it is hoped that more managers will be encouraged to adopt this method. However, neither a single case study nor several necessarily provide a true measure of the relative performance and success of this model. Further research should be done to bring this method to maturity and to compare the efficiency of the method in different types of planning (such as information-strategy, marketing, product-roadmap, knowledge-management, etc.). Moreover, this approach does not focus on finding an optimal deployment but merely addresses prioritizing agility providers. For further research, a goal-programming model can be developed to select in greater detail the combination of agility capabilities and providers which results in optimal levels of agility, subject to cost and other enterprise constraints.

It is acknowledged that the evaluation levels and members involved in any particular implementation will be different, depending on the firm involved. The agility drivers and entrepreneurial objectives and strategies vary from firm to firm. For example, enterprises in high-tech industries, stressing competitive advantage through innovation, may have decided on agility capabilities and providers differently from firms in traditional industries seeking to compete in flexibility, global sourcing and low-cost providers.

Furthermore, according to the comments from the previous case, this approach resolves some of the problems in traditional methods of strategic business planning, having several advantages when compared to previous methods:

1. This method provides a structured procedure for identifying the agility drivers in a business environment, thereby deploying capabilities needed to finally determine the providers that will support or enhance the agility of the enterprise. Furthermore, the case study demonstrated that having providers align with strategy and drivers ensures that the providers can cope with strategic direction and provide a competitive edge for the enterprise.
2. This method gives the analyst more convincing and reliable results. The FAI was expressed in a range of values, providing an overall description of the agility of an enterprise and ensuring that the decision made in the evaluation is not biased. As an example, an agility index having a fuzzy value (0.37, 0.56, 0.75) indicates that the agility level is closer to "Highly Agile," but also not far away from "Agile."
3. This method provides a guiding, dynamic document linking the business strategy of a firm with its environment and outlines details for implementation through continuous process improvement and total quality management.
4. This method provides a first step in preventing a majority of inappropriate assessments and also expedites the eventual financial analysis by highlighting the most important benefits and drawbacks for formulating a comprehensive plan for improvement.

Finally, there are some limitations to the fuzzy-logic approach. The membership function of natural language expression depends on the managerial perspective of the experts, who must be at a strategic level in the enterprise to evaluate the importance of all aspects such as strategy, marketing and technology. Furthermore, competitive situations and requirements vary from one enterprise or industry to another; hence, a company must establish its unique membership function appropriate to its own specific environment and considerations. Moreover, the computation of a fuzzy weighted average is still complicated and not easily appreciated by managers. Fortunately, this calculation has been computerized to increase accuracy while reducing both computation time and the possibility of errors.

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Levels of change		**Merit ratings**		**Relationship-levels**	
Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Extremely Low (EL)	(0, 0.05, 0.15)	Worst (W)	(0, 0.05, 0.15)	Very Low (VL)	(0, 0.1, 0.2)
Very Low (VL)	(0.1, 0.2, 0.3)	Very Poor (VP)	(0.1, 0.2, 0.3)	Low (L)	(0.1, 0.25, 0.4)
Low (L)	(0.2, 0.35, 0.5)	Poor (P)	(0.2, 0.35, 0.5)	Fair (F)	(0.3, 0.5, 0.7)
Fair (F)	(0.3, 0.5, 0.7)	Fair (F)	(0.3, 0.5, 0.7)	High (H)	(0.6, 0.75, 0.9)
High (H)	(0.5, 0.65, 0.8)	Good (G)	(0.5, 0.65, 0.8)	Very High (VH)	(0.8, 0.9, 1.0)
Very High (VH)	(0.7, 0.8, 0.9)	Very Good (VG)	(0.7, 0.8, 0.9)		
Extremely High (EH)	(0.85, 0.95, 1.0)	Excellent (E)	(0.85, 0.95, 1.0)		

Table 1.Fuzzy numbers to approximate linguistic variable values

Drivers	**Capabilities**	**Providers**
Growth of niche market (A D_1)	Sensing /Identifying changes and fast response (AC_1)	Multi-skilled and flexible personnel (AP_1)
Increasing rate of change in product models (A D_2)	Strategic vision (AC_2)	Workforce skill upgrade (AP_2)
Product lifetime shrinkage (A D_3)	Technological ability and appropriate product introduction (AC_3).	Quick new product introduction (AP_3)
Rapidly changing market (A D_4)	Cost-effectiveness (AC_4)	Response to changing market requirements (AP_4)
Increasing pressure on cost (A D_5)	Cooperation and operation efficiency and effectiveness (AC_5)	Products with substantial value-addition (AP_5)
Increasing pressure of global market competition (A D_6)	Product volume/model flexibility (AC_6)	First-time right design (AP_6)
Decreasing new products time to market (A D_7)	Organization/personnel flexibility (AC_7)	Trust-based relations with customers/suppliers (AP_7)
Quicker delivery time and time to market (A D_8)	Product/service design, delivery alacrity and timeliness (AC_8)	Technology awareness (AP_8)
Increasing quality expectation (A D_9)	Fast operation time (AC_9)	Skill and knowledge enhancement (AP_9)
Introduction of new soft technologies (software and methods) (A D_{10})		Concurrent execution of activities (AP_{10})
Environmental pressures (A D_{11})		Information technology and communication (AP_{11})
		Empowerment and decentralized decision-making (AP_{12})
		Cross-functional team (AP_{13})
		Culture of change (AP_{14})

Table 2. Agility-related factors

			Agility capabilities								
			AC_1	AC_2	AC_3	AC_4	AC_5	AC_6	AC_7	AC_8	AC_9
		Merits of agility capabilities / Level of change	G	G	G	F	F	VG	F	P	F
Agility drivers	AD_1	VH	VH	H	H	F	F	VH	H	H	VH
	AD_2	VH	H	H	VH	H	H	H	VH	H	VH
	AD_3	VH	H	H	VH	H	H	F	H	H	VH
	AD_4	VH	H	VH	H	H	H	VH	H	VH	VH
	AD_5	EH	H	F	H	VH	H	H	F	H	H
	AD_6	VH	H	VH	H	VH	VH	H	VH	VH	VH
	AD_7	VH	VH	H	H	F	H	H	H	VH	VH
	AD_8	VH	VH	H	H	F	H	H	H	VH	VH
	AD_9	H	H	F	H	F	VH	F	F	H	F
	AD_{10}	H	H	H	H	H	F	H	H	H	H
	AD_{11}	H	F	H	F	L	F	L	F	F	L

Table 3. Agility capability related to drivers: agile strategies analysis matrix (assigned by general auditor)

		Agility providers													
		AP_1	AP_2	AP_3	AP_4	AP_5	AP_6	AP_7	AP_8	AP_9	AP_{10}	AP_{11}	AP_{12}	AP_{13}	AP_{14}
Merits of agility providers		VG	G	VG	F	G	G	G	VG	VG	G	G	E	F	G
Agility capabilities	AC_1	H	H	VH	H	H	H	L	H	H	F	H	VH	H	H
	AC_2	H	F	H	H	H	H	VH	H	F	H	H	H	F	VH
	AC_3	VH	VH	VH	H	H	VH	F	H	H	H	VH	F	H	H
	AC_4	H	H	H	H	H	H	VH	H	H	H	H	F	F	H
	AC_5	H	H	H	VH	H	VH	H	H	H	VH	H	H	VH	H
	AC_6	VH	H	H	VH	H	H	H	H	H	H	H	H	H	F
	AC_7	VH	H	H	VH	H	H	H	H	H	VH	H	VH	H	H
	AC_8	H	H	H	VH	H	VH	H	H	H	VH	H	H	H	H
	AC_9	VH	H	H	VH	H	VH	H	H	H	VH	H	H	VH	H

Table 4. Agility providers related to capabilities: principle obstacle identification matrix (assigned by general auditor)

Agility capability	Fuzzy average relation-weights	Agility providers	Fuzzy average relation-weights
Sensing /Identifying changes and responding (AC_1).	(0.61, 0.76, 0.92)	Multi-skilled and flexible personnel (AP_1)	(0.60, 0.74, 0.90)
Strategic vision (AC_2).	(0.60, 0.76, 0.91)	Workforce skill upgrade (AP_2)	(0.55, 0.72, 0.88)
Technological ability and appropriate product introduction (AC).	(0.65, 0.79, 0.93)	Quick new product introduction (AP_3)	(0.60, 0.76, 0.91)
Cost-effectiveness (AC_4).	(0.61, 0.77, 0.92)	Response to changing market requirements (AP_4)	(0.63, 0.78, 0.93)
Cooperation and operations efficiency and effectiveness (AC_5).	(0.58, 0.75, 0.91)	Products with substantial value-addition (AP_5)	(0.52 0.70, 0.87)
Product volume/model flexibility (AC_6)	(0.54, 0.73, 0.89)	First-time right design (AP_6)	(0.62, 0.77, 0.93)
Organization/personnel flexibility (AC_7)	(0.46, 0.63, 0.76)	Trust-based relations with customers/suppliers (AP_7)	(0.55, 0.73, 0.89)
Product/service design, delivery alacrity and timeliness (AC_8)	(0.67, 0.82, 0.96)	Technology awareness (AP_8)	(0.54, 0.72, 0.88)
Fast operation time (AC_9)	(0.65, 0.81, 0.95)	Skill and knowledge enhancement (AP_9)	(0.60, 0.75, 0.9)
		Concurrent execution of activities (AP_{10})	(0.60, 0.76, 0.91)
		Information technology and communication (AP_{11})	(0.60, 0.75, 0.9)
		Empowerment and decentralized decision-making (AP_{12})	(0.52, 0.71, 0.88)
		Cross-functional team (AP_{13})	(0.55, 0.73, 0.89)
		Culture of change (AP_{14})	(0.37, 0.58, 0.78)

Table 5. Fuzzy average relation-weights of agility capabilities and providers

Agility providers	Merits of agility provider	(1.0, 1.0, 1.0) (-) $FARWAP_i$	Fuzzy relation-value indexes	Ranking scores
AP_1	(0.3, 0.5, 0.7)	(0.1, 0.26, 0.4)	(0.03, 0.13, 0.28)	0.1808
AP_2	(0.5, 0.65, 0.8)	(0.12, 0.28, 0.45)	(0.06, 0.182, 0.36)	0.2339
AP_3	(0.7, 0.8, 0.9)	(0.09, 0.24, 0.4)	(0.063, 0.192, 0.36)	0.2391
AP_4	(0.5, 0.65, 0.8)	(0.07, 0.22, 0.37)	(0.035, 0.143, 0.296)	0.1929
AP_5	(0.5, 0.65, 0.8)	(0.13, 0.3, 0.48)	(0.065, 0.195, 0.384)	0.2478
AP_6	(0.3, 0.5, 0.7)	(0.07, 0.23, 0.38)	(0.021, 0.115, 0.266)	0.1681
AP_7	(0.5, 0.65, 0.8)	(0.11, 0.27, 0.45)	(0.055, 0.176, 0.36)	0.2305
AP_8	(0.7, 0.8, 0.9)	(0.12, 0.28, 0.46)	(0.084, 0.224, 0.414)	0.2722
AP_9	(0.5, 0.65, 0.8)	(0.1, 0.25, 0.4)	(0.05, 0.163, 0.32)	0.2115
AP_{10}	(0.5, 0.65, 0.8)	(0.09, 0.24, 0.4)	(0.045, 0.156, 0.32)	0.2077
AP_{11}	(0.5, 0.65, 0.8)	(0.1, 0.25, 0.4)	(0.05, 0.163, 0.32)	0.2115
AP_{12}	(0.5, 0.65, 0.8)	(0.12, 0.29, 0.48)	(0.06, 0.189, 0.384)	0.2444
AP_{13}	(0.3, 0.5, 0.7)	(0.11, 0.27, 0.45)	(0.033, 0.135, 0.315)	0.1947
AP_{14}	(0.3, 0.5, 0.7)	(0.22, 0.42, 0.63)	(0.066, 0.21, 0.441)	0.2709

Table 6. Fuzzy merit-relation-value indexes of agility providers

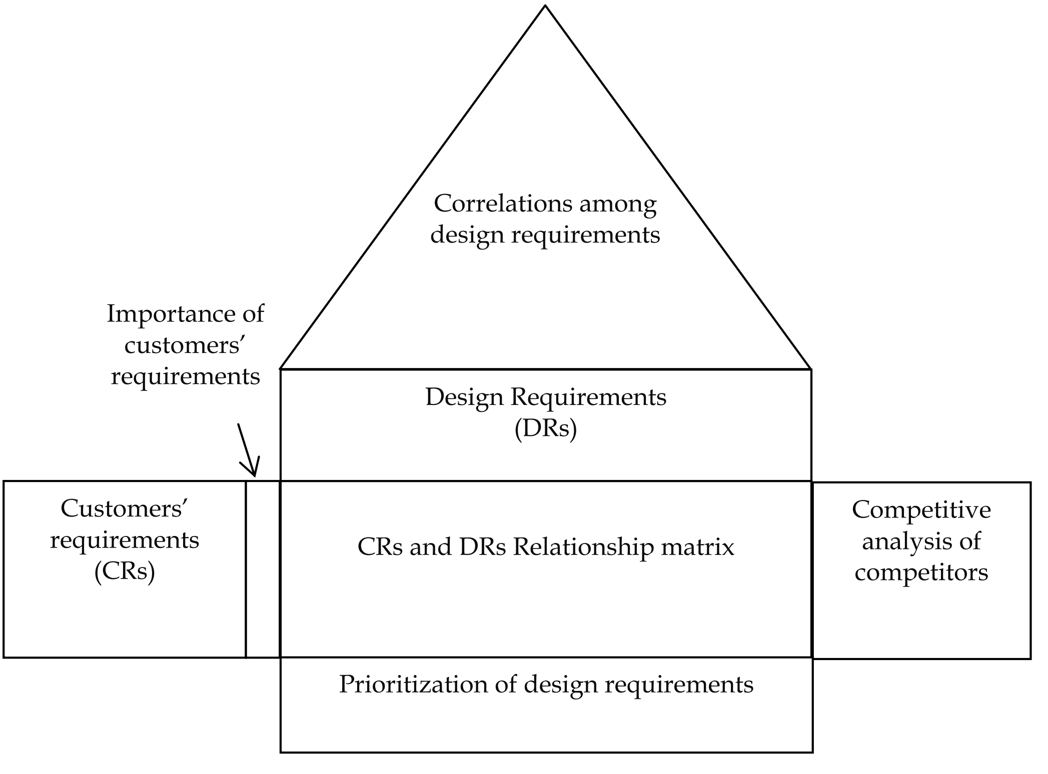


Figure 1. A basic house-of-quality (HOQ) matrix

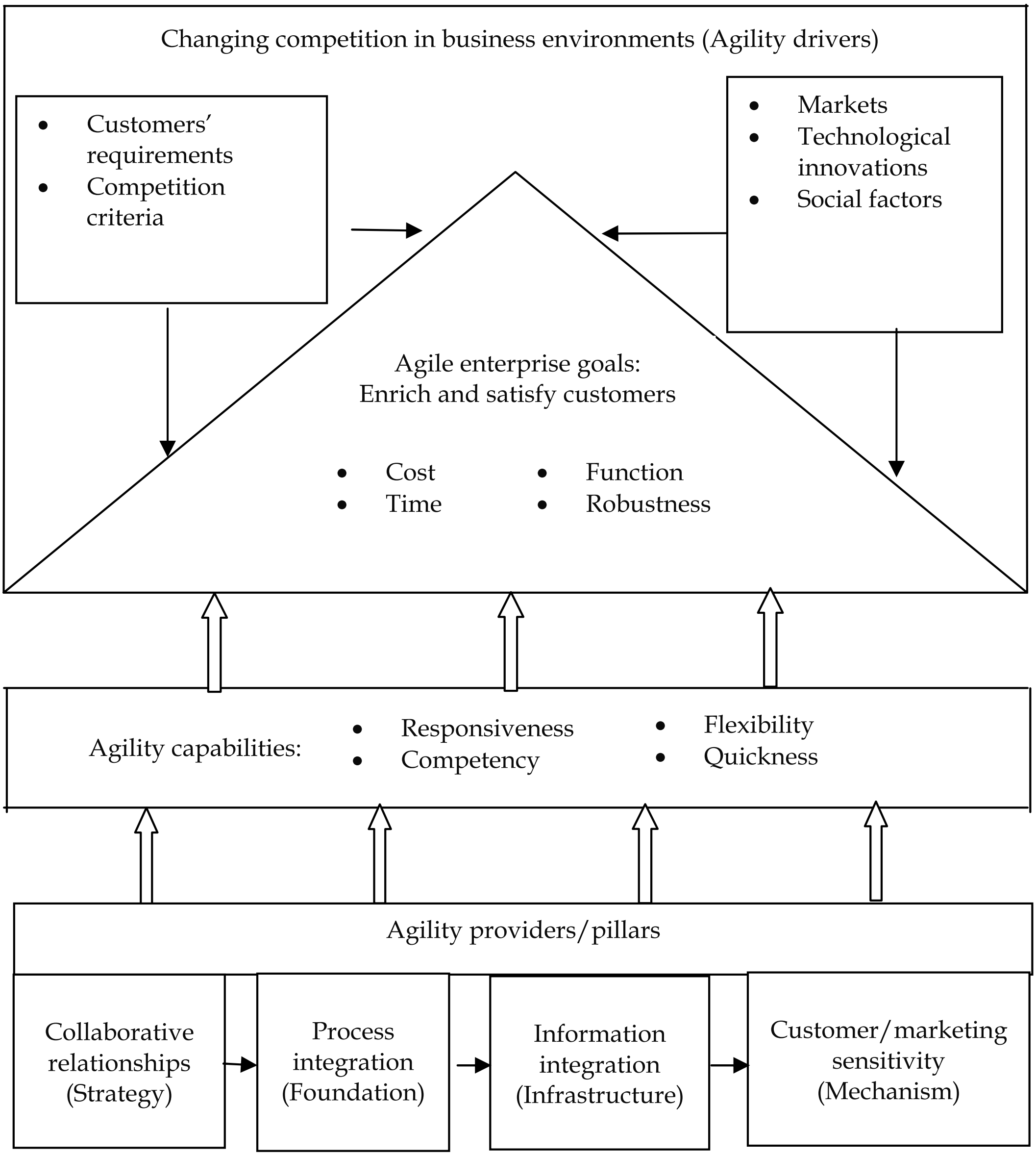
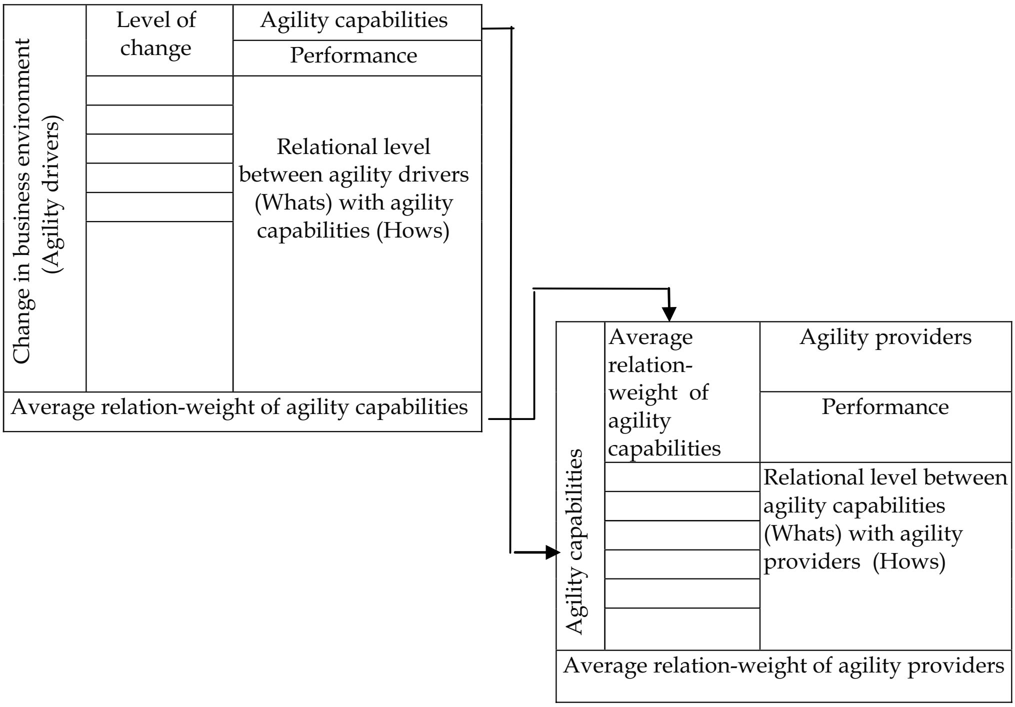


Figure 2. A conceptual framework of an agile enterprise



Matrix for analyzing agile strategies

Matrix for identifying obstacles to agility

Figure 3. A systematic agility-linking model

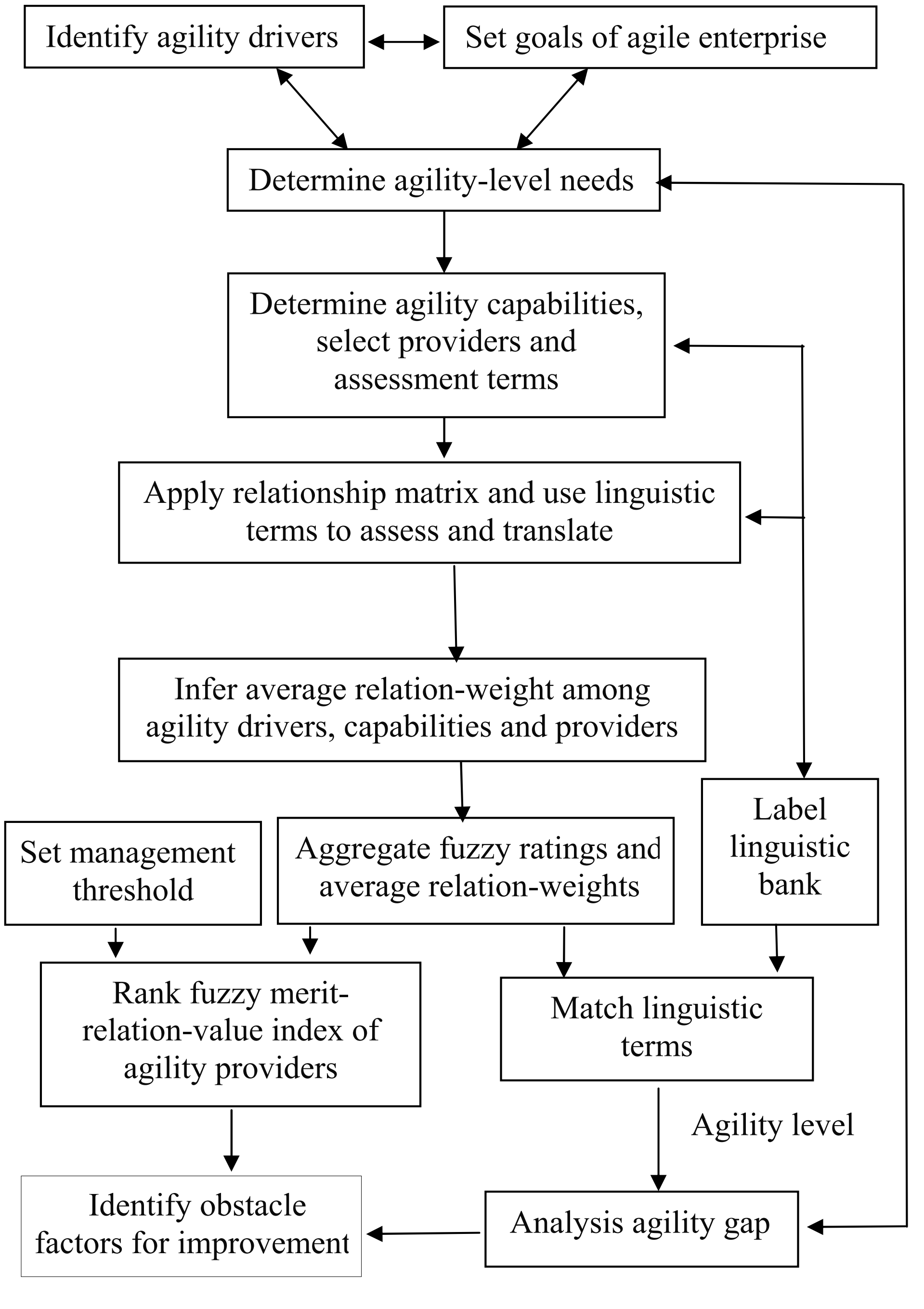
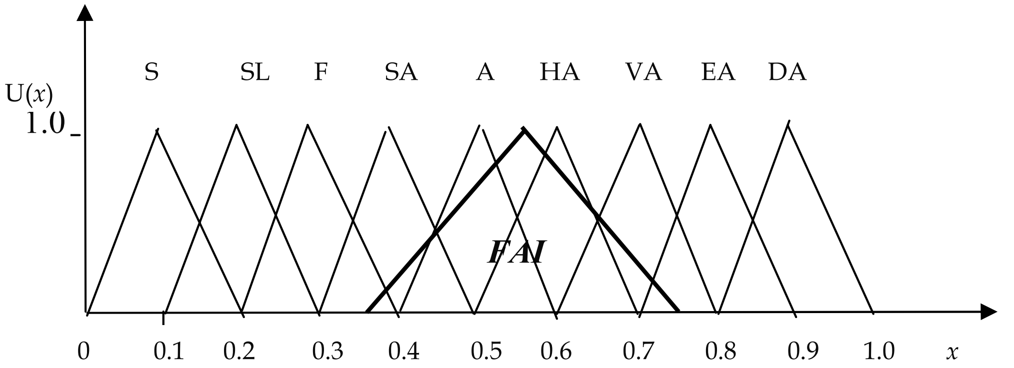


Figure 4. A method for evaluating and achieving agility



[(*S* (0.0, 0.1, 0.2); SL (0.1, 0.2, 0.3); F (0.2, 0.3, 0.4); SA (0.3, 0.4, 0.5);
A (0.4, 0.5, 0.6); *HA* (0.5, 0.6, 0.7); *VA* (0.6, 0.7, 0.8); *EA* (0.7, 0.8, 0.9); *DA* (0.8, 0.9, 1.0)]

Figure 5. Matching fuzzy agility index with linguistic terms

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Optimization of Multi-Tiered Supply Chain Networks with Equilibrium Flows

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1. Introduction

Consider a multi-tiered supply chain network which contains manufacturers, distributors and consumers. A manufacturer located at the top tier of this supply chain is supposed to be concerned with the production of products and shipments to the distributors for profit maximization. In turn, a distributor located in the middle tier of the supply chain is faced with handling and managing the products obtained from manufacturers as well as conducting transactions with consumers at demand markets. The consumer, who is the ultimate user for the product in the supply chain, located at the bottom tier of the supply chain agrees to the prices charged by distributors for the product if the associated business deal is done. The underlying behaviour of manufacturers, distributors and consumers is supposed to compete in a non-cooperative manner. Each decision maker individually wishes to find optimal shipments given the ones of other competitors. The problem of deciding optimal shipments in a supply chain equilibrium network was firstly noted by Nagurney et al. (2002). Dong et al. (2004) developed a supply chain network model where a finite-dimensional variational inequality was formulated for the behaviour of various decision makers. Zhang (2006), in turn, proposed a supply chain model that comprises heterogeneous supply chains involving multiple products and competing for multiple markets.

In this chapter we develop an optimal solution scheme for a multi-tiered supply chain network which contains manufacturers, distributors and consumers. In the multi-tiered supply chain network, there are two kinds of decision-making levels investigated: the management level and the operations level. For the management level, the decision maker wishes to find a set of optimal policies which aim to minimize total cost incurred by the whole supply chain network. For the operations level, assuming the underlying behaviour of the multi-tiered decision makers compete in a non-cooperative manner, each decision maker individually wishes to find optimal shipments given the ones of other competitors. Therefore a problem of deciding equilibrium productions and shipments in a multi-tiered supply chain network can be established. Nagurney et al. (2002) were the first ones to recognize the supply chain equilibrium behaviour, in this chapter, we enhance the modelling of supply chain equilibrium network by taking account of policy interventions at management level, which takes the responses of the decision makers at operations level to the changes made at management level for which a minimal cost of the supply chain can be achieved. A new solution scheme is also developed for optimizing a multi-tiered supply chain network with equilibrium flows.

Optimization for a multi-tiered supply chain network with equilibrium flows can be formulated as a mathematical program with equilibrium constraints (MPEC) where a two-level decision making process is considered. A MPEC program for a general network design problem is widely known as non-convex and non-differentiable. In this chapter, a non-smooth analysis is employed to optimize the policy interventions determined at the management level. The first order sensitivity analysis is carried out for supply chain equilibrium network flow which is determined at the operations level. The directional derivatives and associated generalized gradient of equilibrium product flows (shipments) with respect to the changes of policy interventions made at management level can be therefore obtained. Because the objective function of the multi-tiered supply chain network is non-smooth, a subgradient projection solution scheme (SPSS) is proposed to solve the multi-tiered supply chain network problem with global convergence. Numerical calculations are conducted using a medium-scale supply chain network. Computational results successfully demonstrate the potential of the SPSS approach in solving a multi-tiered supply chain equilibrium network problem with reasonable computational efforts.

The organization of this chapter is as follows. In next section, a MPEC formulation is addressed for a multi-tiered supply chain network with equilibrium flows where a two-level decision making process is considered. The first-order sensitivity analysis for equilibrium flows at operations level is carried out by solving an affine variational inequality. A subgradient projection solution scheme (SPSS), in Section 3, is proposed to globally solve the multi-tiered supply chain network problem with equilibrium flows. In Section 4 numerical calculations and comparisons with earlier methods in solving the supply chain network problem are conducted using a medium-scale network. Good results with far less computational efforts by the SPSS approach are also reported. Conclusions and further work associated are summarized in Section 5.

2. Problem formulation

In this section, a MPEC program is firstly given for a three-tiered supply chain network containing manufacturers, distributors and consumers where a two-level decision making process: the management level and the operations level, is considered. A first-order sensitivity analysis is conducted for which the generalized gradient and directional derivatives of variable of interests at operations level can be obtained. At the management level, suppose strong regularity condition (Robinson, 1980) holds at the variable of interests with respect to the policy interventions which are determined at management level, a one level MPEC program can be established. The directional derivatives for the three-tiered supply chain network can be also therefore found via the corresponding sugbradients.

2.1 Notation

M : a set of manufacturers located at the top tier of the multi-tiered supply chain network.

R : a set of distributors located in the middle tier of the multi-tiered supply chain network.

U : a set of demand markets located at the bottom tier of the multi-tiered supply chain network.

β : a set of policy settings determined at management level in the multi-tiered supply chain network.

x_{ij} : the product flow/shipment between agents at distinct tiers of the multi-tiered supply chain network.

$p_i(\cdot)$: the production cost function for a manufacturer i, $\forall i \in M$.

$h_j(\cdot)$: the handling cost function for a distributor j, $\forall j \in R$.

$t_{1ij}(\cdot)$: the transaction cost function on link (i, j) between manufacturer i and distributor j, $\forall i \in M$ and $\forall j \in R$.

$t_{2jk}(\cdot)$: the transaction cost function on link (j,k) between distributor j and consumers at demand market k; $\forall j \in R$ and $\forall k \in U$.

d_k : the consumptions at the demand market k, $\forall k \in U$.

λ_{1ij} : the market price charged for distributor j by manufacturer i, $\forall i \in M$ and $\forall j \in R$.

λ_{2jk} : the market price charged for demand market k by distributor j, $\forall j \in R$ and $\forall k \in U$.

γ_j : the market clear price for distributor j, $\forall j \in R$.

μ_k : the price at demand market k, $\forall k \in U$.

2.2 Equilibrium conditions for a three-tiered supply chain network

According to Nagurney (1999), optimal production and shipments for manufacturers in a three-tiered supply chain network can be found by solving the following variational inequality formulation. Find the values $x_{ij} \in K_1$, $\forall i \in M, j \in R$ such that

$$\sum_{i \in M}\sum_{j \in R}\left(p_i(X_i) + t_{1ij}(x) - \lambda_{1ij}\right)\left(z - x_{ij}\right) \geq 0 \tag{1}$$

for all $z \in K_1 = \{x_{ij}, i \in M, j \in R\}$ where $X_i = \sum_{j \in R} x_{ij}$.

Akin to inequality (1), the optimal inbound shipments for distributor j, say x_{ij}, from the manufacturer i, and the outbound shipments, say x_{jk}, to the consumers at demand market

k, coincide with the solutions of the following variational inequality. Find values $x_{ij} \in K_1$ and $x_{jk} \in K_2$, $\forall i \in M, j \in R$ and $k \in U$ as well as the market clear price γ_j such that

$$\sum_{i \in M} \sum_{j \in R} \left(\lambda_{1ij} + h_j(X_j) - \gamma_j\right)\left(w - x_{ij}\right) + \sum_{j \in R} \sum_{k \in U} \left(t_{2jk}(x) + \gamma_j - \lambda_{2ij}\right)\left(z - x_{jk}\right)$$

$$+ \sum_{j \in R} \left(\sum_{i \in M} x_{ij} - \sum_{k \in U} x_{jk} \right)\left(\gamma - \gamma_j\right) \geq 0 \tag{2}$$

for all $w \in K_1 = \{x_{ij}, i \in M, j \in R\}$, $z \in K_2 = \{x_{jk}, j \in R, k \in U\}$ and $X_j = \sum_{k \in U} x_{jk}$. The market clear price γ_j in a three-tiered supply chain network is associated with the product flow conservation which holds for each distributor j, $\forall j \in R$ as follows.

$$\sum_{i \in M} x_{ij} \geq \sum_{k \in U} x_{jk} \tag{3}$$

Assuming the underlying behavior of the consumers at demand market k, $\forall k \in U$ competing non-cooperatively with other consumers for the product provided by distributors, in the third tier supply chain network the governing equilibrium condition for the consumptions at demand market k can be, in a similar way to (1) and (2), coincide with the solutions of the following variational inequality in the following manner. Determine the consumptions d_k such that

$$\sum_{j \in R} \sum_{k \in U} \left(\lambda_{2jk} - \mu_k\right)\left(z - x_{jk}\right) \geq 0 \tag{4}$$

for all $z \in K_2 = \{x_{jk}, j \in R, k \in U\}$ and $d_k = \sum_{j \in R} x_{jk}$.

2.3 A three-tiered supply chain network equilibrium model

Consider the optimality conditions given in (1-2) and (4) respectively for manufacturers, distributors and consumers, a three-tiered supply chain network equilibrium model can be established in the following way.

Definition 1. A three-tiered supply chain network equilibrium: The equilibrium state of the supply chain network is one where the product flows between the distinct tiers of the agents coincide and the product flows and prices satisfy the sum of the optimality conditions (1), (2) and (4). □

Theorem 2. A variational inequality for the three-tiered supply chain network model: The equilibrium conditions governing the supply chain network model with competitions are equivalent to the solution of the following variational inequality. Find $(x_{ij}, x_{jk}) \in (K_1, K_2)$ such that

$$\sum_{i\in M}\sum_{j\in R}\left(p_i(X_i)+h_j(X_j)+t_{1ij}(x)-\gamma_j\right)\left(u-x_{ij}\right)+\sum_{j\in R}\sum_{k\in U}\left(t_{2jk}(x)+\gamma_j-\mu_k\right)\left(v-x_{jk}\right)$$

$$+\sum_{j\in R}\left(\sum_{i\in M}x_{ij}-\sum_{k\in U}x_{jk}\right)\left(\gamma-\gamma_j\right)\geq 0 \tag{5}$$

for all $(u,v)\in(K_1,K_2)$, and γ_j is the market clear price for distributor j, $\forall j\in R$.

Proof. Following the Definition 1, the equilibrium conditions for a three-tiered supply chain network in determining optimal productions for manufacturers, optimal inbound and outbound shipments for distributors and optimal consumptions for consumers can be expressed as the following aggregated form of summing up the (1), (2) and (4). Find $(x_{ij}, x_{jk}) \in (K_1, K_2)$ such that

$$\sum_{i\in M}\sum_{j\in R}\left(p_i(X_i)+h_j(X_j)+t_{1ij}(x)-\gamma_j\right)\left(u-x_{ij}\right)+\sum_{j\in R}\sum_{k\in U}\left(t_{2jk}(x)+\gamma_j-\mu_k\right)\left(v-x_{jk}\right)$$

$$+\sum_{j\in R}\left(\sum_{i\in M}x_{ij}-\sum_{k\in U}x_{jk}\right)\left(\gamma-\gamma_j\right)\geq 0$$

for all $(u,v)\in(K_1,K_2)$, and γ_j is the market clear price for distributor j, $\forall j\in R$.□

2.4 A generalized variational inequality

In the supply chain network equilibrium model (5), suppose $p_i(\cdot), h_j(\cdot), t_{1ij}(\cdot)$ and $t_{2jk}(\cdot)$, $\forall i\in M, j\in R$ and $k\in U$ are continuous and convex. Let

$$K=K_1\cup K_2\cup\left\{(x_{ij},x_{jk}):\sum_{i\in M}x_{ij}\geq\sum_{k\in U}x_{jk},\forall j\in R\right\} \tag{6}$$

And

$$F(\cdot)=(p_i,h_j,t_{1ij},t_{2jk})_{i\in M,j\in R,k\in U} \tag{7}$$

a standard variational inequality for (5) can be expressed as follows. Determine $X\in K$ such that

$$F^t(X)(Z-X) \geq 0 \tag{8}$$

$\forall Z \in K$ where the superscript t denotes matrix transpose operation.

2.5 A link-based variational inequality

Regarding the inequality (8), a link-based variational inequality formulation for a three-tiered supply chain network equilibrium model can be expressed in the following way. Let s and d respectively denote total productions and demands for the supply chain. Let q denote the equilibrium link flow in the supply chain network, x denote the path flow between distinct tiers, Λ and Γ respectively denote the link-path and origin/destination-path incidence matrices. The set K in (6) can be re-expressed in the corresponding manner.

$$K = \{q : q = \Lambda x, \Gamma x = d, s = d, x \geq 0\} \tag{9}$$

Let f denote the corresponding cost for link flow q. A link-based variational inequality formulation for (8) can be expressed as follows. Determine values $q \in K$ such that

$$f^t(q)(z-q) \geq 0 \tag{10}$$

for all $z \in K$.

2.6 A MPEC programme

Optimal policy settings for a three-tiered supply chain equilibrium network (5) can be formulated as the following MEPC program.

$$\underset{\beta,q}{Min} \quad \Theta_0(\beta,q) \tag{11}$$

$$\text{subject to} \quad \beta \in \Omega\,,\ q \in S(\beta)$$

where Ω denotes the domain set of the decision variables of the policy settings which are determined at management level, and $S(\cdot)$ denotes the solution set of equilibrium flows which is determined at operations level in a three-tiered supply chain network, which can be solved as follows.

$$f^t(\beta,q)(z-q) \geq 0 \tag{12}$$

for all $z \in K$.

2.7 Sensitivity analysis by directional derivatives at operations level

Following the technique employed (Qiu & Magnanti, 1989), the sensitivity analysis of (12) at operations level in a three-tiered supply chain network can be established in the following way. Let the changes in link or path flows with respect to the changes in the policy settings made at management level be denoted by q' or x', the corresponding change in path flow cost be denoted by F', and let the demand market price be denoted by μ. Introduce

$$K' = \{q' : \exists x' \; such \quad that \quad q' = \Lambda x', \Gamma x' = 0, and \quad x' \in K_0\} \tag{13}$$

where

$$K_0 = \left\{ x' : \begin{array}{lll} (i).x' \quad free, & & if \quad x > 0 \\ (ii).x' = 0, & & if \quad F > \mu \\ (iii).x' = 0, & if \quad F = \mu, and \quad x = 0 & with \quad F' > 0 \\ (iv).x' > 0, & if \quad F = \mu, and \quad x = 0 & with \quad F' \le 0 \end{array} \right\} \tag{14}$$

Therefore the directional derivatives of (12) can be obtained by solving the following affine variational inequality. Find $q' \in K'$,

$$\left(\nabla_\beta f(\beta,q)\beta' + \nabla_q f(\beta,q)q'\right)^t (z - q') \ge 0 \tag{15}$$

for all $z \in K'$ where $\nabla_\beta f$ and $\nabla_q f$ are gradients evaluated at (β, q) when the changes in the policy settings made at management level are specified. According to Rademacher's theorem (Clarke, 1980) in (11) the solution set $S(\cdot)$ is differentiable almost everywhere. Thus, the generalized gradient for $S(\cdot)$ can be denoted as follows.

$$\partial S(\beta^*) = conv\{q'(\beta^*) = \lim_{k\to\infty} \nabla q(\beta^k) : \beta^k \to \beta^*, \nabla q(\beta^k) exists\} \tag{16}$$

where conv denotes the convex hull.

2.8 A one level mathematical program

At the management level, suppose strong regularity condition (Robinson, 1980) holds at the variable of interests with respect to the policy interventions, due to inequality (15) a one level MPEC program can be established in the following way. Suppose the solution set $S(\cdot)$ is locally Lipschitz, a one level optimization problem of (11) is to

$$\underset{\beta}{Min} \quad \Theta(\beta) \tag{17}$$

$$\text{subject to} \quad \beta \in \Omega$$

In problem (17), as it seen obviously from literature (Dempe, 2002; Luo et al., 1996), $\Theta(\cdot)$ function is a non-smooth and non-convex function with respect to the policy settings determined at management level in a three-tiered supply chain network because the solution set of equilibrium flow $S(\cdot)$ at operations level may not be explicitly expressed as a closed form.

3. A non-smooth optimization model

Due to non-differentiability of the solution set $S(\cdot)$ in (17), in this section, we propose an optimal solution scheme using a non-smooth approach for the three-tiered supply chain network problem (17). In the following we suppose that the objective function $\Theta(\cdot)$ is semi-smooth and locally Lipschitz. Therefore the directional derivatives of $\Theta(\cdot)$ can be characterized by the generalized gradient, which are also specified as follows.

Definition 3 <Semi-smoothness, adapted from Mifflin (1977)> We say that $\Theta(\cdot)$ is semismooth on set Ω if $\Theta(\cdot)$ is locally Lipschitz and the limit

$$\lim_{v \in \partial\Theta(\beta + t\bar{h}), \bar{h} \to h, t \downarrow 0} \{v\bar{h}\} \tag{18}$$

exists for all $\bar{h}$. □

Theorem 4 <Directional derivatives for semismooth functions, adapted from Qi & Sun (1993)> Suppose that $\Theta(\cdot)$ is a locally Lipschitzian function and the directional derivative $\Theta'(\beta; h)$ exists for any direction h at β. Then

(1). $\Theta'(\cdot; h)$ is Lipscitizian;

(2). For any h, there exists a $v \in \partial\Theta(\beta)$ such that

$$\Theta'(\beta; h) = vh \tag{19}$$

□

The generalized gradient of $\Theta(\cdot)$ can be expressed as follows.

$$\partial\Theta(\beta^*) = conv\left\{\lim_{k \to \infty} \nabla\Theta(\beta^k) : \beta^k \to \beta^*, \nabla\Theta(\beta^k) exists\right\} \tag{20}$$

According to Clarke (1980), the generalized gradient is a convex hull of all points of the form $\lim \nabla\Theta(\beta^k)$ where the subsequence $\{\beta^k\}$ converges to the limit value β^*. And the gradients in (20) evaluated at (β^k, q^k) can be expressed as follows.

$$\nabla\Theta(\beta^k) = \nabla_\beta \Theta_0(\beta^k, q^k) + \nabla_q \Theta_0(\beta^k, q^k) q'(\beta^k) \tag{21}$$

where the directional derivatives $q'(\beta^k)$ can be obtained from (15).

3.1 A subgradient projection solution scheme (SPSS)

Consider the non-smooth problem (17), a general solution by an iterative subgradient method can be expressed in the following manner. Let $\Pr_\Omega(\beta) \in \Omega$ denote the projection of β on set Ω such that

$$\left\| x - \Pr_{\Omega}(x) \right\| = \inf_{y \in \Omega} \left\| x - y \right\| \tag{22}$$

thus we have

$$\beta^{k+1} = \Pr_{\Omega}(\beta^k - tv), v \in \partial\Theta(\beta^k) \tag{23}$$

and

$$t = \lambda \frac{\Theta(\beta^k) - \Theta(\beta^*)}{\left\| v \right\|^2}, v \in \partial\Theta(\beta^k), \quad 0 < a \le \lambda \le 2 - b, b > 0 \tag{24}$$

where the local minimum point β^* is supposed to be known and $\lambda = \frac{1}{k}$. Since the subgradient method is a non-descent method with slow convergence as commented and modified from literature, in this chapter, we are not going to investigate the details of these progress. On the other hand, a new globally convergent solution scheme for problem (17) is proposed via introducing a matrix in projecting the subgradient of the objective function onto a null space of active constraints in order to efficiently search for feasible points. In this proposed solution scheme, consecutive projections of the subgradient of the objective function help us dilate the direction provided by the negative of the subgradient which greatly improves the local solutions obtained. In the following, Rosen's gradient projection matrix is introduced first.

Definition 5. <Projection matrix> A $n*n$ matrix G is called a projection matrix if $G = G^t$ and $GG = G$. □

Thus the proposed Subgradient Projection Solution Scheme (SPSS) for the non-smooth problem (17) can be presented in the following way.

Theorem 6. <Subgradient Projection Solution Scheme> In problem (17), suppose $\Theta(\cdot)$ is lower semi-continuous on the domain set Ω. Given a β^1 such that $\Theta(\beta^1) = \alpha$, the level set $S_\alpha(\Omega) = \{\beta : \beta \in \Omega, \Theta(\beta) \le \alpha\}$ is bounded and Θ is locally Lipschitzian and semi-smooth on the convex hull of S_α. A sequence of iterates $\{\beta^k\}$ can be generated in accordance with

$$\beta^{k+1} = \Pr_{\Omega}(\beta^k - tG_k v^k), \quad v^k \in \partial\Theta(\beta^k) \tag{25}$$

where t is the step length which minimize Θ^k and the projection matrix G_k is of the following form.

$$G_k = I - M_k^t (M_k M_k^t)^{-1} M_k \tag{26}$$

In (26) M_k is the gradient of active constraints in (17) at β^k, where the active constraint gradients are linearly independent and thus M_k has full rank. The search direction h^k can be determined in the following form.

$$h^k = G_k v^k \tag{27}$$

Then the sequence of points $\{\beta^k\}$ generated by the SPSS approach is bounded whenever $G_k \nabla\Theta(\beta^k) \neq 0$.

Proof. For any x and y in the set Ω, by definition of the projection, we have

$$\left\|\Pr_\Omega(x) - \Pr_\Omega(y)\right\| \leq \left\|x - y\right\| \tag{28}$$

thus for β^{k+1} we have

$$\left\|\beta^{k+1} - \beta^*\right\|^2 = \left\|\Pr_\Omega(\beta^k - th^k) - \beta^*\right\|^2 \tag{29}$$

$$\leq \left\|\beta^k - th^k - \beta^*\right\|^2$$

$$= \left\|\beta^k - \beta^*\right\|^2 + t^2\left\|h^k\right\|^2 - 2t(\beta^k - \beta^*)^t h^k$$

let

$$C = 2t(\beta^k - \beta^*)^t h^k - t^2\left\|h^k\right\|^2 \tag{30}$$

then (29) can be rewritten as

$$\left\|\beta^{k+1} - \beta^*\right\|^2 \leq \left\|\beta^k - \beta^*\right\|^2 - C$$

Since Θ is locally Lipschitzian and semi-smooth on the convex hull of S_α, by convexity we have

$$(\beta^k - \beta^*)^t \nabla\Theta(\beta^k) \geq \Theta(\beta^k) - \Theta(\beta^*)$$

for any ε_1 and $\varepsilon_2 \in [0,2]$ there exists λ such that $0 \leq \varepsilon_1 \leq \lambda \leq 2 - \varepsilon_2$, let

$$t = \lambda \frac{\Theta(\beta^k) - \Theta(\beta^*)}{G_k\left\|\nabla\Theta(\beta^k)\right\|^2} \tag{31}$$

In (30), it can be rewritten as

$$C = 2\lambda \frac{\Theta(\beta^k) - \Theta(\beta^*)}{G_k \left\|\nabla\Theta(\beta^k)\right\|^2} (\beta^k - \beta^*)^t G_k \nabla\Theta(\beta^k) - \lambda^2 \left(\frac{\Theta(\beta^k) - \Theta(\beta^*)}{G_k \left\|\nabla\Theta(\beta^k)\right\|^2} \right)^2 \left\|G_k \nabla\Theta(\beta^k)\right\|^2$$

$$\geq 2\lambda \frac{\left(\Theta(\beta^k) - \Theta(\beta^*)\right)^2}{\left\|\nabla\Theta(\beta^k)\right\|^2} - \lambda^2 \frac{\left(\Theta(\beta^k) - \Theta(\beta^*)\right)^2}{\left\|\nabla\Theta(\beta^k)\right\|^2} \text{ (due to convexity)}$$

$$= \left(\frac{\Theta(\beta^k) - \Theta(\beta^*)}{\left\|\nabla\Theta(\beta^k)\right\|} \right)^2 (2\lambda - \lambda^2) \geq 0$$

thus we have $\left\|\beta^{k+1} - \beta^*\right\|^2 \leq \left\|\beta^k - \beta^*\right\|^2$ for $k = 1,2,3...$ It implies $\left\|\beta^k - \beta^*\right\|$ is monotonically decreasing and $\left\|\beta^k - \beta^*\right\| \leq \left\|\beta^1 - \beta^*\right\|$. □

Theorem 7. Following Theorem 6, when $G_k \nabla\Theta(\beta^k) = 0$, if all the Lagrange multipliers corresponding to the active constraint gradients in (17) are positive or zeros, it implies the current point is a Karush-Kuhn-Tucker (KKT) point. Otherwise choose one negative Lagrange multiplier, say η_j, and construct a new $\hat{M}_k$ of the active constraint gradients by deleting the *j*th row of $\hat{M}_k$, which corresponds to the negative component η_j, and make the projection matrix of the following form

$$\hat{G}_k = I - \hat{M}_k^t (\hat{M}_k \hat{M}_k^t)^{-1} \hat{M}_k \tag{32}$$

The search direction then can be determined by (27) and the results of Theorem 6 hold.□

Theorem 8 <Convergence of SPSS> In problem (17) assuming that $\Theta(\cdot)$ is lower semi-continuous on the domain set Ω, given a β^1 such that $\Theta(\beta^1) = \alpha$, the level set $S_\alpha(\Omega) = \{\beta : \beta \in \Omega, \Theta(\beta) \leq \alpha\}$ is bounded and Θ is locally Lipschitzian and semi-smooth on the convex hull of S_α. Let $\{\beta^k\}$ be the sequence of points generated by the SPSS approach as described above. Then every accumulation point β^* satisfies

$$0 \in \partial\Theta(\beta^*) \tag{33}$$

Proof. We proof this theorem by contradiction. Supposing $0 \notin \partial\Theta(\beta^*)$, by definition there is no subgradient $\nabla\Theta(\beta^k) = 0$ in the convex hull of S_α, whose accumulation point is β^*. Then there is a $t^* > 0$ minimizing $\Theta(\beta^* - th^*)$ and a $\delta > 0$ such that

$\Theta(\beta^*) = \Theta(\beta^* - t^* h^*) + \delta$ and $\beta^* - t^* h^*$ is an interior point of S_α. By the mean value theorem, for any β^k we have

$$\Theta(\beta^k - t^* h^k) = \Theta(\beta^* - t^* h^*) + \nabla\Theta(\xi^k)^t \left(\beta^k - \beta^* - t^*(h^k - h^*)\right) \tag{34}$$

where $\xi^k = \beta^* - t^* h^* + \varepsilon\left(\beta^* - \beta^k - t^*(h^* - h^k)\right)$ for some $0 < \varepsilon < 1$. Following the Bozano-Weierstrass theorem that there is a subsequence $\left\{\beta^{kn}\right\}$ of $\left\{\beta^k\right\}$ that converges to β^*, then $\left\{\nabla\Theta(\xi^{kn})\right\}$ converges to $\nabla\Theta(\beta^* - t^* h^*)$ and $\left\{\beta^{kn} - \beta^* - t^*(h^{kn} - h^*)\right\}$ converges to zero. For sufficiently large kn, the vector ξ^{kn} belongs to the convex hull of S_α and

$$\Theta(\beta^{kn} - t^* h^{kn}) \le \Theta(\beta^* - t^* h^*) + \frac{\delta}{2} = \Theta(\beta^*) - \frac{\delta}{2} \tag{35}$$

Let t_{kn}^* be the minimizing point of $\Theta(\beta^{kn} - t_{kn} h^{kn})$. Since $\left\{\Theta(\beta^{kn})\right\}$ is monotone decreasing and converges to $\Theta(\beta^*)$, we have

$$\Theta(\beta^*) < \Theta(\beta^{kn} - t_{kn}^* h^{kn}) \le \Theta(\beta^{kn} - t^* h^{kn}) \le \Theta(\beta^*) - \frac{\delta}{2} \tag{36}$$

a contradiction. Therefore every accumulation point β^* satisfies $0 \in \partial\Theta(\beta^*)$. □

Corollary 9 <Stopping condition> If β^k is a KKT point for problem (17) satisfying Theorem 8 then the search process may stop; otherwise a new search direction at β^k can be generated according to Theorem 6. □

3.2 Implementation Steps

In this subsection, ways in solving the non-smooth problem (17) for a three-tiered supply chain network involving the management level and the operations level are conducted by steps in the following manner.

Step 1. At the management level, start with the initial policy setting β^k, and set index $k = 1$.

Step 2. At the operations level, solve a three-tiered supply chain equilibrium problem by means of (5) when the decision variables of policy β^k are specified at management level. Find the subgradients for equilibrium products and shipments by means of (15), and obtain the generalized gradient for the objective function of the supply chain network via (21).

Step 3. Use the SPSS approach to determine a search direction.

Step 4. If $G_k \nabla\Theta(\beta^k) \ne 0$, find a new β^{k+1} by means of (25) and let $k \leftarrow k+1$. Go to Step 2. If $G_k \nabla\Theta(\beta^k) = 0$ and all the Lagrange multipliers corresponding to the active constraint gradients are positive or zeros, β^k is a KKT point and stop. Otherwise, follow the results of Theorem 6 and find a new projection matrix and go to Step 3.

4. Numerical calculations

In this section, we used a 9-node network from literature (Bergendorff et al., 1997) as an illustration for a three-tiered supply chain network problem with equilibrium flows. In Fig. 1, a three-tiered supply chain is considered in which there are two pairs of manufacturers and consumers, and 4 product-mix pairs: [1,3], [1,4], [2,3] and [2,4], can be accordingly specified. In Fig. 1, manufacturers are denoted by nodes 1 and 2, distributors are denoted by nodes 7 and 8, and the consumers are denoted by nodes 3 and 4. The corresponding demand functions can be determined in the following manner: $d_{1,3} = 10 - 0.5\mu_{1,3}$, $d_{1,4} = 20 - 0.5\mu_{1,4}$, $d_{2,3} = 30 - 0.5\mu_{2,3}$ and $d_{2,4} = 40 - 0.5\mu_{2,4}$. In this numerical illustration a new set of link tolls at the management level is to be determined optimally such that traffic congestion on the connected links between various distinct tiers can be consistently reduced. In Fig. 1 let A_a and k_a be given parameters and specified as a pair (A_a, k_a) near each link. The transaction costs on links are assumed in the following way.

$$t_a(q_a) = A_a(1 + 0.15(\frac{q_a}{k_a})^4) \tag{37}$$

Computational results are summarized in Table 1 for a comparative analysis at two distinct initial tolls. Three earlier well-known methods in solving the network design problem are also considered: the sensitivity analysis method (SAB) proposed by Yang & Yagar (1995), the Genetic Algorithm (GA) proposed by Ceylan & Bell (2004), and recently proposed Generalized Projected Subgradient (GPS) method by Chiou (2007). As it seen in Table 1, the SPSS approach improved the minimal toll revenue at two distinct initial tolls nearly by 18% and 16% while the SAB method only did by 8% and 6%. The SPSS approach successfully outperformed the GA method and newly proposed GPS method by 4% and 2% on average in reduction of minimal toll revenue. For two sets of initial tolls the relative difference of the minimal toll revenue did the SPSS is within 0.07 % while that did the SAB method is within nearly 0.3%. Regarding the efficiency of the SPSS approach in solving the three-tiered supply chain network with equilibrium flows when the toll settings are considered at management level, the SPSS approach required the least CPU time in all cases. Furthermore, as it obviously seen in Table 1, various sets of resulting tolls can be found due to the non-convexity of the MPEC problem. Computational efforts on all methods mentioned in this chapter were conducted on SUN SPARC SUNW, 900 MHZ processor with 4Gb RAM under operating system Unix SunOS 5.8 using C++ compiler gnu g++ 2.8.1.

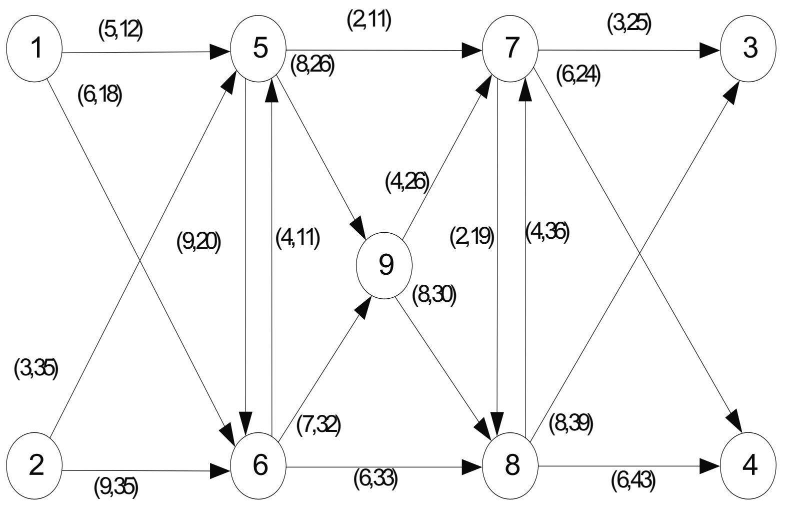

Figure 1. 9-node supply chain network

5. Conclusions and discussions

This chapter addresses a new solution scheme for a three-tiered supply chain equilibrium network problem involving two-level kinds of decision makers. A MPEC program for the three-tiered supply chain network problem was established. In this chapter, from a non-smooth approach, firstly, we proposed a globally convergent SPSS approach to optimally solve the MPEC program. The first order sensitivity analysis for the three-tiered supply chain equilibrium network was conducted. Numerical computations using a 9-node supply chain network from literature were performed. Computational comparative analysis was also carried out at two sets of distinct initial data in comparison with earlier and recent proposed methods in solving the multi-tiered supply chain network problem. As it shown, the proposed SPSS approach consistently made significant improvements over other alternatives with far less computational efforts. Regarding near future work associated, a multi-tiered supply chain network optimization problem with multi-level decision makers is being investigated as well as implementations on large-scale supply chain networks.

6. Acknowledgements

Special thanks to Taiwan National Science Council for financial support via grant NSC 96-2416-H-259-010-MY2

	1st set initials				2nd set initials			
	SAB	**GA**	**GPS**	**SPSS**	**SAB**	**GA**	**GPS**	**SPSS**
Initial toll (in $)	2.0	2.0	2.0	2.0	5.5	5.5	5.5	5.5
Initial revenue (in $)	1223	1223	1223	1223	1198	1198	1198	1198
$\beta_{(1,5)}$	0.5	2.9	0	0	2.5	3.2	0	0
$\beta_{(1,6)}$	0.3	1.2	0.5	1.2	3.2	3.0	0.4	2.1
$\beta_{(2,5)}$	1.2	0	1.6	1.2	1.2	1.2	1.8	1.5
$\beta_{(2,6)}$	0.4	0	1.4	0.4	0	0	1.5	0.9
$\beta_{(5,6)}$	0	2.5	0	2.1	0	0	0.4	1.8
$\beta_{(5,7)}$	8.6	7.6	5.6	7.8	6.3	1.6	5.2	7.5
$\beta_{(5,9)}$	0.7	1.4	3.7	0.7	2.7	0.3	3.5	0.5
$\beta_{(6,5)}$	0	2.8	0	0	0	0	0.2	0
$\beta_{(6,8)}$	1.3	0	3.2	1.3	0	0	3.1	1.1
$\beta_{(6,9)}$	0	0	0	0	1.5	2.2	0.9	0.5
$\beta_{(7,3)}$	0.6	1.7	0.6	0.6	1.2	1.2	0	0
$\beta_{(7,4)}$	0.4	1.8	0.2	0.4	0.4	3.4	0	0
$\beta_{(7,8)}$	0	0	1.2	0	1.2	1.1	1.1	0.8
$\beta_{(8,3)}$	0	0	1.1	0	1.1	0	1.1	0.7
$\beta_{(8,4)}$	0.6	1.2	0.6	1.8	0.6	0.6	0	1.8
$\beta_{(8,7)}$	0	0	2.2	0.6	0.8	0	2.2	0.6
$\beta_{(9,7)}$	0.9	1.5	0	1.9	0.9	2.7	1.2	2.4
$\beta_{(9,8)}$	0	0	3.2	0	1.3	1.8	3.5	0.8
Revenue (in $)	**1120.5**	**1048.9**	**1026.7**	**1005.5**	**1123.5**	**1050.7**	**1027.1**	**1004.8**
cpu time (in sec)	**132**	**258**	**84**	**7**	**154**	**263**	**85**	**6**

Table 1. Computational results for 9-node supply chain network

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14

Parameterization of MRP for Supply Planning Under Lead Time Uncertainties

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1. Introduction

Efficient replenishment planning is a very important problem in Supply chain management. A poor inventory control policy leads to overstocking or stockout situations. In the former, the generated inventories are expensive and in the later there are shortages and penalties due to unsatisfied customer demands.
Material Requirements Planning (MRP) is a commonly accepted approach for replenishment planning in major companies (Axsäter, 2006). The MRP software tools are accepted readily, the majority of industrial decision makers are familiar with them through all the existing production control system software. MRP software has a well developed information system and has been proven over time.
However, MRP is based on the supposition that the demand and lead times are known. This premise of deterministic environment seems somewhat off base since most production occurs stochastically. Component and semi-finished product lead times and finished product demands are rarely forecasted reliably. This is because there are some random factors such as machine breakdowns, transport delays, customer demand variations, etc. Therefore, in real life, the deterministic assumptions embedded in MRP are often too limited.
Fortunately, the MRP approach can be adapted for replenishment planning under uncertainties by searching optimal values for its parameters. This problem is called MRP parameterization under uncertainties.
The planned lead times are parameters of MRP. For the case of random lead times, the planned lead times are calculated as the sum of the forecasted and *safety lead times*. These safety times are obtained as a trade-off between overstocking and stockout while minimizing the total cost. The search for optimal values of safety lead times, and, consequently, for planned lead times, is a crucial and challenging issue in Supply chain management with MRP approach.
In this chapter, we present a methodology for optimal calculation of planned lead times in the MRP approach. This methodology was developed in our previous works (Dolgui et al., 1995; Dolgui, 2001; Dolgui & Louly, 2002; Louly & Dolgui, 2002; Louly & Dolgui, 2004,

Louly et al., 2007) for supply chains with random lead times where holding and backlogging costs are not negligible.

2. Inventory control in supply chains

Supply chain management is a collection of functional activities that are repeated many times throughout the process through which raw materials are transformed into finished products (Ballou, 1999). An illustration of a Supply chain is given in Fig. 1.

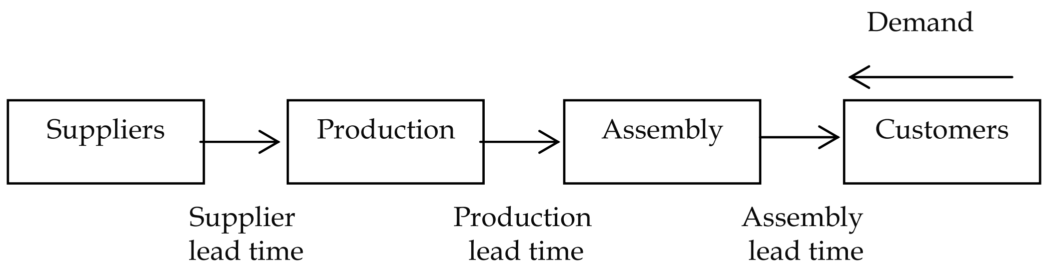

Figure 1. Supply chain

As reported in number of papers, various sources of lead time uncertainties may exist along this chain. To avoid these uncertainties, the companies use safety stocks (safety lead times), which are rather expensive. Therefore, it is desirable to develop special methods of supply planning which focus on the stochastic properties of lead times (Maloni & Benton, 1997).

Supply management in industrial applications is mainly based on Material Requirements Planning (MRP), which provides a framework for inventory control. In the MRP approach, an important distinction is drawn between demand for the end product, i.e. independent demand, and demand for one of its items, i.e. dependent demand (Baker, 1993). The independent demands are known or forecasted by the methods which are developed in the framework of "sales forecasting". The dependent demands can be calculated from the independent ones by using Bill of Material and planned lead times.

Under MRP logic, time is viewed in discrete intervals called *time buckets*. The lead time is equal to the elapsed time buckets from the order release date to the delivery (procurement, production, etc.) of the corresponding item. The lot size is the quantity of items to be ordered.

The MRP method is based on the deterministic calculation: all the orders of items are released at the latest possible moment, so total cost will automatically be minimal. But, if random factors exist, the meaning of "at the latest possible moment" is uncertain. In this case, for each specific value of MRP parameters (concretely: planned lead times) we can have a backlog or overstock probability. The larger the probability of backlog is, the bigger the average backlogging cost over time. The same is true for overstock, the larger the probability of overstock is, the greater the holding cost. Therefore, a challenging problem is MRP parameterization, in particular, the choice of optimal values for planned lead times.

3. Related works

Yeung et al. (1998) propose a review on parameters having an impact on the effectiveness of MRP systems under stochastic environments. Yücesan & De Groote (2000) did a survey on supply planning under uncertainties, but they focused on the impact of the production management under uncertainty on the lead times by observing the service level. Process uncertainties are considered in (Koh et al., 2002; Koh & Saad, 2003).

The problem of MRP parameterization under lead time uncertainties has been often studied via simulation. For example the study of Whybark & Williams (1976) suggests that a safety lead time's mechanism may perform better than that of a safety stock in a multi-level production-inventory system when the production and replenishment times are stochastic. Nevertheless, Grasso & Taylor (1984) reached another conclusion and prefer safety stocks for both quantity and lead-time uncertainties. Weeks (1981) developed a single-stage model with tardiness and holding costs in which the processing time is stochastic and demand is deterministic. The author proves that this is equivalent to the standard "Newsboy" problem. Gupta & Brennan (1995) show that lead time uncertainty has a large influence on the total inventory management cost. Ho & Ireland (1998) illustrate that lead time uncertainty affects stability of a MRP system no matter what lot-sizing method used or demand forecast error obtained. The statistics from simulations by Bragg et al. (1999) demonstrate that the lead times influence the inventories substantially. Molinder (1997) study the problem of planned lead times (safety lead time/safety stock) calculation via simulation and proposes a simulated annealing algorithm to find appropriate safety stocks and/or safety lead times. The simulations show that the overestimated planned lead times is conducive to excessive inventory, and underestimated planned lead times introduce shortages and delays. (Grubbström, & Tang, 1999) study optimal safety stocks in single and multi-level MRP systems, assuming the time interval of end item demand to be stochastic.

For serial multilevel production systems, i.e. where the previous level supplies the next and only one supplier is at each level, Yano (1987a,b) suggests an approach to determine optimal planned lead times for MRP. In this study, the lead times are stochastic, and finished product demand is fixed. The author presents a general procedure for two stage systems based on a single-period continuous inventory control model. The objective was to minimize the sum of inventory holding costs, rescheduling costs arising from tardiness at intermediate stages, and backlogging cost for the finished product. One of the main obstacles for this approach consists in the difficulties to express the objective function in a closed form for more than two stages.

In assembly systems there are several suppliers at each stage, and so, there is dependence among the different component inventories at the same stage. Yano (1987c) considers a particular problem for two-level assembly systems with only two types of components at stage 2 and one type of components at stage 1. The delivery times for the three components are stochastic continuous variables. The problem is to find the planned lead times for MRP minimizing the sum of holding and tardiness costs. A single period model and an optimization algorithm were developed. Tang & Grubbström (2003) consider a two component assembly system with stochastic lead times for components and fixed finished product demand. This study is similar to (Yano, 1987c). However, here, the process time at level 1 is also assumed to be stochastic, the due date is known and the optimal planned lead times are smaller than the due date. The objective is to minimize the total stockout and inventory holding costs. The Laplace transform procedure is used to capture the stochastic properties of lead times. The optimal safety lead times, which are the difference between planned and expected lead times are derived.

Another interesting single period model was proposed in (Chu et al., 1993) which deals with a punctual fixed demand for a single finished product. The model gives optimal values of the component planned lead times for such a one-level assembly system with random component procurement times.

Wilhelm & Som (1998) studied a two-component assembly system using queuening models and showed that a renewal process can be used to describe the end-item inventory level evolution. The optimization of several component stocks is replaced by the optimization of finished product stock. To perform this replacement, a simplified supply policy for component ordering was introduced. Another multi-period model is proposed in (Gurnani et al., 1996) for assembly systems with two types of components and the lead time probability distributions are limited to two periods. In (Dolgui & Louly, 2002; Louly & Dolgui, 2004), a similar one-level planning problem with random lead times and fixed demand is studied, but for a dynamic multi-period case. The authors give a novel mathematical formulation and propose a generalized Newsboy model which gives the optimal solution under the assumption that the lead times of the different types of components follows the same distribution probability, and the unit holding costs are identical. In Louly et al. (2007) the authors generalize their studies of 2002 and 2004. They present a more universal case, when the unit holding costs aren't the same for all components and the component lead times are not i.i.d. random variables.

4. MRP approach

4.1 The basic principles of MRP systems

The goal of MRP is to determine a replenishment schedule for a given time horizon. For example, let's consider the following bill of materials - BOM (see Fig. 2) for a finished product. The needs for the finished product are given by the Master Production Schedule – MPS (Fig. 3), and those for the components are deduced from BOM explosion (Dolgui et al., 2005).

Let's introduce the following notation:

$I(i)$ inventory for the period i,

$N(i)$ net needs for the period i,

$G(i)$ gross needs for the period i,

$Q(i)$ released orders for the period i,

$\Delta\tau$ planned lead time.

The available inventory $I(1)$ for the period 1 is given. For each subsequent need, the value is calculated from the net needs of the previous period:

$$I(i) = \max\{0, -N(i-1)\}, \tag{1}$$

net needs of the period i are obtained as follows:

$$N(i) = G(i) - I(i), \tag{2}$$

The released order quantity:

$$Q(i) = \max\{0, N(i - \Delta\tau)\}\,. \tag{3}$$

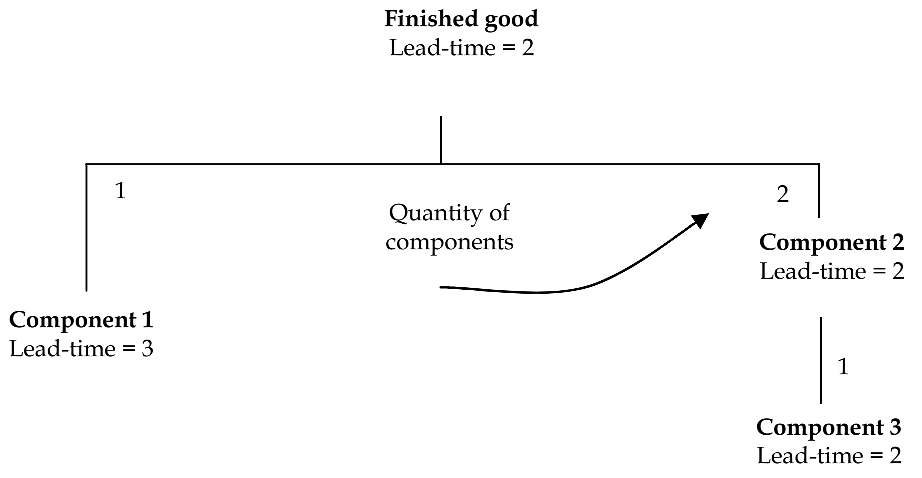

Figure 2. Bill of materials

	Period	1	2	3	4	5	6	7	8	9	10
Level 0 Finished good Lead time = 2	Gross need (MPS)	0	0	0	50	10	40	20	30	50	60
	Available inventory	20	20	20	20	0	0	0	0	0	0
	Net need	-20	-20	-20	30	10	40	20	30	50	60
	Manufacturing/order	0	30	10	40	20	30	50	60	0	0
	Quantity = 1										
	Period	1	2	3	4	5	6	7	8		
Level 1 Component 1 Lead time = 3	Gross need (MPS)	0	30	10	40	20	30	50	60		
	Available inventory	100	100	70	60	20	0	0	0		
	Net need	-100	-70	-60	-20	0	30	50	60		
	Manufacturing/order	0	0	30	50	60	0	0	0		
	Quantity = 2										
	Period	1	2	3	4	5	6	7	8		
Level 1 Component 2 Lead time = 2	Gross need (MPS)	0	60	20	80	40	60	100	120		
	Available inventory	140	140	80	60	0	0	0	0		
	Net need	-140	-80	-60	20	40	60	100	120		
	Manufacturing/order	0	20	40	60	100	120	0	0		
	Quantity = 1										

Figure 3. Master Production Schedule (MPS)

4.2 MRP under uncertainties

The main problem which often arises with MRP systems is derived from the uncertainties (Nahmias, 1997; Vollmann et al., 1997) especially demand and lead time uncertainty (see Fig. 4).

	Period	1	2	3	4	5
Level 0 Finished Good Lead time = 2 +/- 1	Gross need (MPS)	0	0	20	15	0
	Available inventory	20	20	20	0	0
	Net needs	-20	-20	0	15	0
	Manufacturing/order		15			

Demand uncertainty

Lead-time uncertainty

Figure 4. Input data uncertainties

The demand uncertainty means that the demand isn't exactly known in advance and, so the planned quantities for a period may be different from the actual demand. The lead time uncertainty means that the actual lead time may be different from planned lead time, so an order planned for a period may not arrive at the appropriate date.

As aforementioned, in literature, the majority of publications are devoted to the MRP parameterization under customer demand uncertainties. As to random lead times, the number of publications is modest in spite of their significant importance. The motivation of this chapter is to contribute to the development of new efficient methods for MRP parameterization under lead time uncertainties (see Fig. 5).

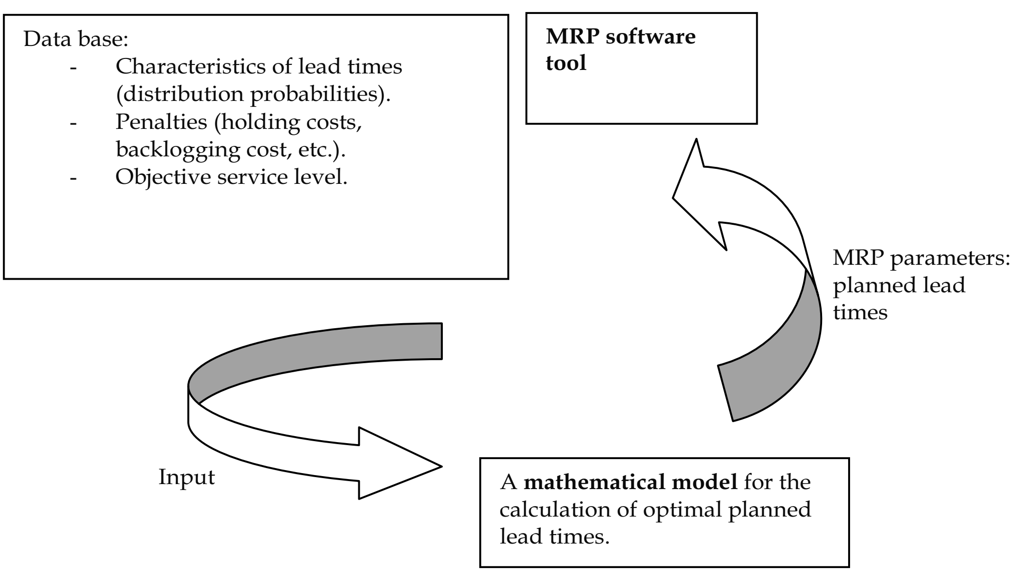

Figure 5. Proposed approach for MRP parameterization

The core of this approach is the calculation of planned (safety) lead times. When we increase these parameters, the stocks increase also. However, stocks are expensive. In contrast, if the planned lead times are underestimated, the risk of stockout and consequently the backlogging cost increases along with decreasing the service level. The goal is to find the planned lead time values which provide a trade-off between holding and backlogging costs while minimizing the total cost under random actual lead times. In the next section, we suggest a mathematical model for this optimization.

5. MRP parameterization

5.1 Mathematical model description

In the MRP approach, replenishment order dates, i.e. release dates, for each component are calculated for a series of discrete time intervals (time buckets) based on the demand and taking into account a fixed planned lead time: the release date is equal to the due date minus the planned lead time. For the case of random actual lead times, in industry, a supply reliability coefficient (≥ 1) is assigned to each supplier. The planned lead times for MRP are calculated by multiplying the contractual lead time by the corresponding supplier reliability coefficient. The choice of these coefficients (which give safety lead times) is based on past experience. However, this approach is subjective and can be non optimal if we need to minimize the total cost for an MRP system. The supplier reliability coefficients (safety lead times and so planned lead times) can be calculated more precisely taking into account inventory holding and backlogging costs, with a inventory control model. Such an inventory control model must be simple (to be solvable), but representative, integrating all major factors influencing the planned lead time calculation.

For component planned lead time calculation for assembly systems with several types of components and random component lead times, we have introduced (Dolgui & Louly, 2002) the following model and assumptions. This model will help us to solve the considered problem of MRP parameterization, i.e. to find optimal planned lead times for components when the actual lead times are random variables. Fig. 6 gives an illustration of the suggested abstract model.

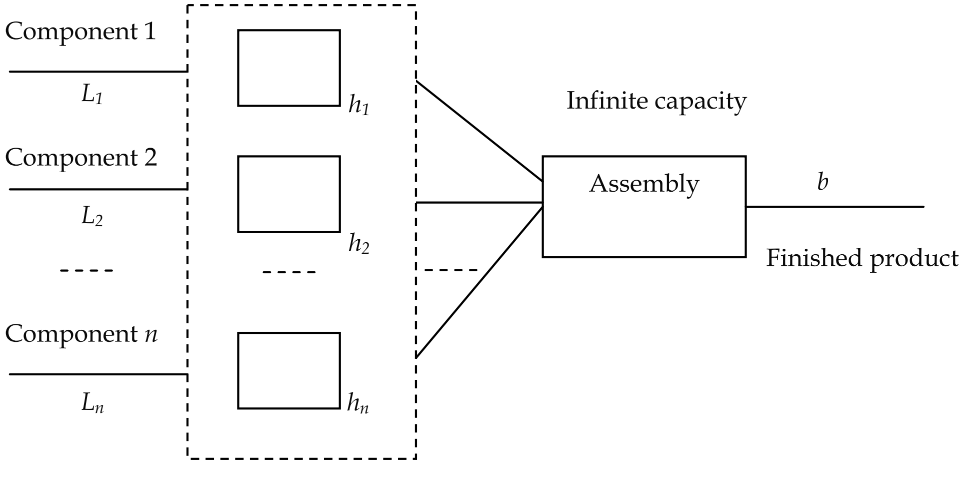

Figure 6. Inventory control model for component planned lead time calculation

For this model, we assume that the finished product demand per period is known and constant as well as the assembly capacity is infinite. Several types of components are needed to assembly one finished product. The unit holding cost per period for each type of component (h_i) and the unit backlogging cost (b) for the finished product are known. The lead times (L_i) for orders made at different periods for the same type of component i are independent and identically distributed discrete random variables. The distribution of probabilities for the different types of components can be not identical. These distributions are known, and their upper values are finite.

The finished products are delivered at the end of each period and unsatisfied demands are backordered and have to be treated later (when sufficient numbers of components of each type are in stock). The supply policy for components is Lot for Lot: one lot of each type of component is ordered at the beginning of each period.

Because the supply policy is the Lot for Lot and the demand is considered as constant, the same quantities of components are ordered at the beginning of each period. Thus, only planned lead times are unknown parameters for this model. Hence, they are the decision variables in our optimisation approach. The model considers random component lead times and also the dependence among inventories of the different components suitable for assembly systems (when there is a stockout of only one component, consequently, there is no possibility to assemble the finished product).

To simplify the equations, without lost of generality, we assume that the finished product demand is equal to one unit per period, and that one finished product is assembled from one unit of each type of component.

Let's use the following model notations:

1_f function equal to 1 if f is true, and 0 otherwise,

n number of types of components used for the assembly of one product,

$E[.]$ mathematical expectation operator,

h_i unit holding cost for the component i per period,

b unit backlogging cost for the finished product per period,

k reference of a period (period index),

L_i lead time of the components i (discrete random variable),

L_i^k lead time of the components i ordered at period k (discrete random variable),

u_i upper value of the lead time for components i ($1 \le L_i \le u_i$; $i = 1, 2, ..., n$); $u = \max_{i=1,...,n} (u_i)$,

N_i^k number of orders for the component i that have not yet arrived at the end of the period k,

N_i steady state number of orders for the component i that have not yet arrived at the end of a period,

X vector of the decision variables $(x_1, ..., x_n)$,

Z^+ function equal to the maximum of Z and 0: $\max(Z,0)$.

Note that:

i. Considering that the component ordered quantities are the same for all periods, the planned lead time multiplied by the ordered quantity, which is equal to the finished product demand, gives also the initial inventory for the corresponding component.

ii. The optimal planned lead times do not depend on the finished product demand (the same values of optimal planned lead times will be obtained for different demand amounts, if the demand is constant and other characteristics of the problem are fixed).

iii. Given the fact that the order quantities are constant, i.e. the same for all periods, the crossing of orders does not complicate the problem.

iv. Taking into consideration the objective of this study – to calculate optimal planned lead times for MRP controlled assembly systems under lead time uncertainties - the assumptions on the fixed demand and infinite assembly capacity are necessary and natural simplifications.

v. Taking into account the assumptions on the constant demand and infinite capacity of the assembly system, we are in a Just in Time (JIT) environment, i.e. there is no stocking of finished products.

vi. Considering that the component lead times cannot exceed u_i $(i = 1,2,...,n)$, the random variables N_i^k and N_i can have only the following values: 0, 1, 2, …, $u_i - 1$.

vii. The orders are given at the beginning of each period and delivered components are used at the ends of periods (so an order made at period *k* can be used at the end of the same period *k*, if the actual lead time is equal to 1).

Let's introduce the following additional notations:

$$F_{N_i}(j) = \Pr(N_i \le j),$$

$X = (x_1, x_2, ..., x_n)$ are decision variables, the value $x_i = 0$ signifies that the component i is ordered at the beginning of the target period (i.e. when assembly must be made),

$$H = b + \sum_{i=1}^{n} h_i .$$

As shown in (Louly et al., 2007), the objective function and constraints for this multi-period model for the optimization of planned lead –times can be formulated as follows:

$$C(X,N) = \sum_{i=1}^{n} h_i\big(x_i - E(N_i)\big) + H \sum_{j\ge 0} \Big(1 - \prod_{i=1}^{n} F_{N_i}(x_i + j)\Big), \tag{4}$$

subject to:

$$0 \le x_i \le u_i - 1 , \quad i = 1,2,\ldots,n . \tag{5}$$

The maximal value of component i lead time is equal to u_i, so only the previous u_i-1 orders may not yet be received. Earlier orders have already arrived, therefore: $0 \le N_i \le u_i - 1$.

$$N_i = \sum_{j=1}^{u-1} 1_{L_i^{u-j} > j}, \quad i = 1,\cdots,n , \tag{6}$$

where

L_i^s is s-th variable L_i (these variables are iid).

The main difficulty of the optimization problems (4)–(5) is that the decision variables, x_i, $i = 1, \cdots, n$, are integers and the objective function is non linear. Thus, this is a complex optimization problem.

5.2 Optimization algorithm

For the problem (4) – (5), we propose the approach illustrated in Fig. 7. From practical point of view, an approximate solution of this problem can be sufficient. So we developed several techniques to calculate lower and upper limits for the value of decision variables. By applying these techniques we reduce the space of admissible values for these variables. Often, the obtained space is relatively small, so an approximate solution is relatively easy to find.

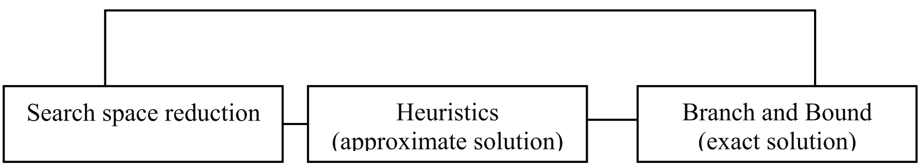

Figure 7. Optimization techniques

The proposed techniques for reduction of the space of admissible values for decision variables are also useful as a pre-processing procedure for an exact optimization algorithm (Branch and Bound in our case). The smaller the search space for the exact procedure is, the quicker the solution can be found.

Pre-processing procedure to reduce search space.

We propose a pre-processing procedure which should be used before optimisation.

Let's present the space of all feasible solutions by [A, B], where A= ($a_1, a_2, \ldots, a_n$), B = (b_1, b_2, …, b_n), where a_i, b_i are minimal and maximal possible values for x_i. We will show some techniques that reduce these intervals: $a_i \le x_i \le b_i$, $i = 1, \cdots, n$.

We proved (Louly et al., 2007) that the optimal solution X= $(x_1, x_2, \ldots, x_n)$ satisfies the following conditions:

$$\max(1 - \frac{h_i}{b}, \frac{b}{H}) \le F_i(x_i), \tag{7}$$

$$F_i(x_i - 1) \le 1 - \frac{h_i}{H}. \tag{8}$$

Therefore, the maximum value of x_i which satisfies the condition (8) gives a upper limit b_i, and the minimum value of x_i which satisfies the condition (7) gives a lower limit a_i for this decision variable x_i. Then, the optimal value of x_i must respect the following relation: $a_i \le x_i \le b_i$.

The pre-processing procedure based on the verification of the conditions (7) and (8) can reduce the search space before applying any optimisation algorithm.

Dominance properties.

We use a Branch & Bound approach to find the optimal values of the parameters x_i, $a_i \le x_i \le b_i$, $i = 1, \cdots, n$.

It is known that dominance properties can improve a Branch & Bound algorithm.

In our previous works, we have introduced the following partial increment functions:

$$G_i^+(X) = C(x_1, \ldots, x_i + 1, \ldots, x_n) - C(x_1, \ldots, x_i, \ldots, x_n), \tag{9}$$

$$G_i^-(X) = C(x_1, \ldots, x_i - 1, \ldots, x_n) - C(x_1, \ldots, x_i, \ldots, x_n). \tag{10}$$

The following two dominance properties (i) and (ii) were proved in (Louly & Dolgui, 2007):

If $G_i^+(A) < 0$, then each solution X of [A, B] with $x_i = a_i$ is dominated. (11)

If $G_i^-(B) < 0$, then each solution X of [A, B] with $x_i = b_i$ is dominated. (12)

These dominance properties can be used to develop efficient cut procedures. Indeed, after the division of a node, in a Branch and Bound algorithm, two son-nodes (descendants) are created. For each son-node, some cuts can be applied to reduce again the corresponding search spaces before the next branching.

Lower bounds on the objective function.

Since, we use a Branch and Bound algorithm to solve the optimization problem (4) – (5), we need efficient Lower bounds for each tree node and root. In this sub-section, we develop these bounds.

In (Louly et al., 2007), we have the two following Lower Bounds on the objective function in the space [A, B]:

$$LB_1 = C(A) + \sum_{i=1}^{n} (b_i - a_i) \min\left(G_i^+(b_1, \ldots, b_{i-1}, a_i, \ldots, a_n), 0\right), \tag{13}$$

$$LB_2 = C(B) + \sum_{i=1}^{n} (b_i - a_i) \min\left(G_i^-(a_1, \ldots, a_{i-1}, b_i, \ldots, b_n), 0\right), \tag{14}$$

$$LB_3 = \begin{cases} f(a_{\min}), \text{ if } \mathrm{x}_0 < a_{\min}, \\ f(\mathrm{x}_0), \quad \text{if } a_{\min} < b_{\max}, \\ f(b_{\max}), \text{ if } \mathrm{x}_0 > b_{\max}, \end{cases} \tag{15}$$

where,

$$f(x) = \sum_{i=1}^{n} \hat{h}\left(x - E(N_i)\right) + (b + n\hat{h}) \sum_{k \ge 0} \left(1 - \prod_{i=1}^{n} \hat{F}(x+k)\right),$$

$$\hat{h} = \min_{i=1,\dots,n} h_i ,$$

$$\hat{F}(x) = \max_{i=1,\dots,n} F_i(x) ,$$

$$a_{\min} = \min_{i=1,\dots,n} a_i ,$$

$$b_{\max} = \max_{i=1,\dots n} b_i .$$

The parameter x_0 is the largest integer which verifies the following expression:

$$\hat{F}(x-1) \le \left(\frac{b}{b+n\hat{h}}\right)^{1/n} \le \hat{F}(x) \cdot$$

The following lower bound will be used in the Branch and Bound:

$$LB = \max\,(LB_1, LB_2, LB_3) \tag{16}$$

Node extension procedure.

A Branch and Bound (B&B) algorithm is based on the design of an enumeration tree. In our algorithm, each node of the enumeration tree represents a set of feasible solutions. Let [A, B] be a node of this tree. The descendants of this node are obtained by dividing (partitioning) the corresponding space [A, B] into two smaller subspaces [A, B1] and [A1, B] as follows:

- we choose i such that $i = \arg\max\,(b_i - a_i)$,
- then, the descendent [A, B1] (respectively [A1, B]) is the subspace given by the vectors A and B1 (resp. A1 and B) for whom the i-th component satisfies $a_i \le x_i \le \frac{a_i + b_i}{2}$ (resp. $\frac{a_i + b_i}{2} + 1 \le x_i \le b_i$).

After applying this node extension procedure for the node [A, B] we obtain two son-nodes [A, B1] and [A1, B], each with smaller space of feasible solutions.

Lower Cut and Upper Cut procedures.

For each node before applying a node extension procedure some cuts are executed. The aim is to reduce the space of feasible solutions which is associated with the node to be divided.

For our algorithm, the principle is simple, as mentioned above a node corresponds to a search space [A, B]. The cut procedure reduces the solution space [A, B] replacing A (respectively B) by a larger (respectively smaller) vector. This is equivalent to cutting a part of the search space [A, B]. We introduce two procedures: one for cutting small values (Lower Cut procedure) and second for cutting large values (Upper Cut procedure) of the corresponding decision variables. The reduction scheme is the same for these two procedures and they return "true" when the subset [A, B] is entirely dominated (i.e. by applying the cuts we completely eliminated the node [A, B]).

Upper bound calculation procedure.
This procedure to calculate an Upper Bound is a variant of depth first search that consists in choosing the node [A, B] to be partitioned (divided) that has the best solution at one of its two extremities (A or B).

6. Conclusion and further research

We studied an MRP parameterization problem for assembly systems under component lead time uncertainties. This problem of inventory control and production planning under uncertainties is crucial for industry. Most publications are devoted to customer demand uncertainties. In contrast, lead time uncertainties seem not be sufficiently studied, in particular, for the control of component inventories for assembly systems with random component procurement times (lead times). Nevertheless, many of industrial applications exist where the component lead times are random.

For the case of assembly systems with random lead times and a random demand, if the demand and component lead times are independent random variables, the following decomposition can be made. The finished product stock and the component stocks for assembly can be considered as independent. So, our approach is still valid for MRP parameterization: for the finished product a safety stock is calculated using the standard approaches, and the component planned lead times are deducted from the model proposed in this chapter.

Of course, it would be better to develop a model which takes into account the dependence between the stock of the finished product and component stocks in the case of random demand and lead times. This will be one path for our future research, perhaps using the conjecture of (Kim et al., 2006). This conjecture, suggested for a single-item model, affirms that the behaviour of an inventory/production system where both demand and lead times are random can be evaluated by modelling for three particular cases with: (i) deterministic demand and lead time, (ii) random demand and deterministic lead time, and (iii) random lead time and deterministic demand.

Further research should be focused on the development of a more effective Branch- and-Bound procedures for the general case of these single-level assembly systems. Another path for future work would deal with multilevel assembly systems, i.e. with multi-level bill of material. Logically, difficulty will increase because of dependence among levels in addition to the dependence among inventories.

7. Acknowledgements

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15

Design, Management and Control of Logistic Distribution Systems

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1. Introduction

Nowadays global and extended markets have to process and manage increasingly differentiated products, with shorter life cycles, low volumes and reducing customer delivery times. Moreover several managers frequently have to find effective answers to one of the following very critical questions: in which kind of facility plant and in which country is it most profitable to manufacture and/or to store a specific mix of products? What transportation modes best serve customer points of demand, which can be located worldwide? Which is the best storage capacity of a warehousing system or a distribution center (DC)? Which is the most suitable safety stock level for each item of a company's product mix? Consequently logistics is assuming more and more importance and influence in strategic and operational decisions of managers of modern companies operating worldwide.

The Council of Logistics Management defines logistics as "the part of supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements". Supply Chain Management (SCM) can be defined as "the integration of key business processes from end-user through original suppliers, that provides product, service, and information that add value for customers and other stakeholders" (Lambert et al., 1998). In accordance with these definitions and with the previously introduced variable and critical operating context, Figure 1 illustrates a significant conceptual framework of SCM proposed by Cooper et al. (1997) and discussed by Lambert et al. (1998). Supply chain business processes are integrated with functional entities and management components that are common elements across all supply chains (SCs) and determine how they are managed and structured. Not only back-end and its traditional

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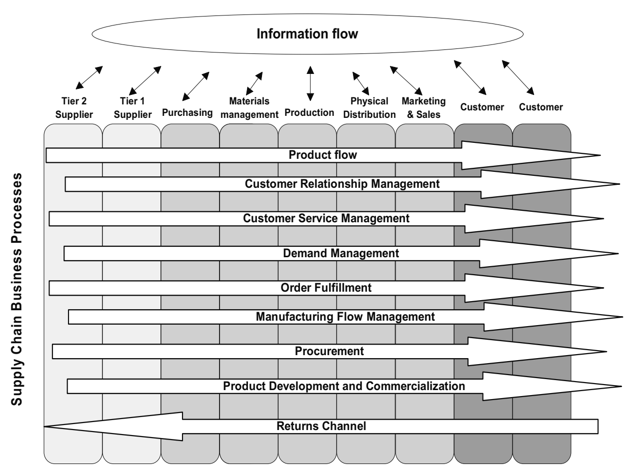
stand-alone modelling is addressed, but the front-end beyond the factory door is also addressed through information sharing among suppliers, supplier's suppliers, customers, and customers' customers.
In the modern competitive business environment the effective integration and optimization of the planning, design, management and control activities in SCs are one of the most critical issues facing managers of industrial and service companies, which have to operate in strongly changing operating conditions, where flexibility, i.e. the ability to rapidly adapt to changes occurring in the system environment, is the most important strategic issue affecting the company success.
As a consequence the focus of SCM is on improving external integration known as "channel integration" (Vokurka & Lummus, 2000), and the main goal is the optimization of the whole chain, not via the sum of individual efficiency maximums, but maximising the entire system thanks to a balanced distribution of the risks between all the actors.
The modelling activity of production and logistic systems is a very important research area and material flows are the main critical bottleneck of the whole chain performance. For this reason in the last decade the great development of research studies on SCM has found that new, effective supporting decisions models and techniques are required. In particular a large amount of literature studies (Sule 2001, Manzini et al. 2006, Manzini et al. 2007a, b, Gebennini et al. 2007) deal with facility management and facility location (FL) decisions, e.g. the identification of the best locations for a pool of different logistic facilities (suppliers, production plants and distribution centers) with consequent minimization of global investment, production and distribution costs. FL and demand allocation models and methods object of this chapter are strongly associated with the effective management and control of global multi-echelon production and distribution networks.



Planning and Control	Product structure
Work structure	Management methods
Organization structure	Power and leadership structure
Product flow facility structure	Risk and reward structure
Informatics flow facility structure	Culture and attitude

Figure 1. Supply Chain Management (SCM) framework and components

A few studies propose operational models and methods for the optimization of SCs, focusing on the effectiveness of the global system, i.e. the whole chain, and the determination of a global optimum. The purpose of this chapter is the definition of new perspectives for the effective planning, design, management , and control of multi-stage distribution system by the introduction of a new conceptual framework and an operational supporting decision platform. This framework is not theoretical, but deals with the tangible Production Distribution Logistic System Design (PDSD) problem and the optimization of logistic flow within the system. As a consequence the proposed optimization models have been applied to real case studies or to multi-scenarios experimental analysis, and the obtained results are properly discussed.

The remainder of this chapter is organized as follows: Section 2 presents and discusses principal literature studies on SC planning and design. Section 3 presents and describes the conceptual framework proposed by the authors for providing an effective solutions to the PDSD problem. Section 4 presents mixed integer programming models and a case study for the so called static design of a logistic network. Similarly Section 5 and 6 discuss about the fulfillment system design problem and the dynamic facility location. Finally, Section 7 concludes with directions for future research.

2. Review of the literature

In recent years hundreds of studies have been carried out on various logistics topics, e.g. enterprise resource planning (ERP), warehousing, transportation, e-commerce, etc. These studies follow the well-known definition of SC: "it consists of supplier/vendors, manufacturers, distributors, and retailers interconnected by transportation, information and financial infrastructure. The objective is to provide value to the end consumer in terms of products and services, and for each channel participant to garner a profit in doing so" (Shain & Robinson, 2002). As a consequence SCM is the act of optimizing all activities through the supply chain (Chan & Chan 2005).

Literature contributions in SC planning and management discriminate between the strategic level on the one hand, and the tactical and operational levels on the other (Shen 2005, Manzini et al. 2007b). The strategic level deals with the configuration of the logistic network in which the number, location, capacity, and technology of the system facilities are decided. The most important tactical and operational decisions are inventory management decisions and distribution decisions within the SC, e.g. deciding the aggregate quantities and material flows for purchasing, processing, and distribution of products. Shen (2005) affirms that in order to achieve important costs savings, many companies have realized that the generic SC should be optimized as a whole, i.e. the major cost factors that impact on the performance of the chain should be considered jointly in the decision model. Even though several studies have proposed innovative models and methods to support logistic decision making concerning what to produce, where, when, how, and for which customer, etc., as yet no effective and low cost tools have been developed capable of integrating logistic problems and decision making at different levels as a support for management in industrial and service companies. Recent studies of Manzini et al. (2007b), Monfared & Yang (2007), and Samaranayake & Toncich (2007) introduce the first basis for the definition and development of effective supporting decision tools which integrates these three different levels of planning. In particular the tool proposed by Manzini et al. (2007b) is based on an original conceptual framework described in next section. In logistics and SCM the high level of significance of the generic FL problem can be obtained by taking of simultaneous decisions regarding design, management, and control of a distribution network:

1. location of new supply facilities in a given set of demand points. The demand points correspond to existing customer locations;
2. allocation of demand flows to available or new suppliers;
3. configuration of the transportation network for supplying demand needs: i.e. the design of paths from suppliers to customers and simultaneously the management of routes and vehicles.

The problem of finding the best of many possible locations can be solved by several qualitative and efficiency site selection techniques, e.g. ranking procedures and economic models (Byunghak & Cheol-Han 2003). These techniques are still largely influenced by subjective and personal opinions (Love et al. 1988, Sule 2001). Consequently, the problems of an effective location analysis are generally and traditionally categorized into one broad classes of quantitative and quite effective methods described in Table 1 (Love et al. 1988, Sule 2001, Manzini et al. 2007a).

In particular the location allocation is the problem to determine the optimal location for each of the *m* new facilities and the optimal allocation of existing facility requirements to the new facilities so that all requirements are satisfied, that is, when the set of existing facility locations and their requirements are known. Literature presents several models and approaches to treating location of facilities and allocation of demand points simultaneously. In particular, Love et al. (1988) discuss the following site-selection LAP models: set-covering (and set-partitioning models); single-stage, single-commodity distribution model; and two-stage, multi-commodity distribution model which deals with the design for supply chains composed of production plants, DCs, and customers. The LAP models consider various aspects of practical importance such as production and delivery lead times, penalty cost for unfulfilled demand, and response times different customers are willing to tolerate (Manzini et al. 2007a, b). Passing to the NLP one of the most critical decision deals with the selection of specific paths from different nodes in the available network.

So-called "dynamic location models" consider a multi-period operating context where the demand varies between different time periods. This configuration of the problem aims to answer three important questions. Firstly, *where* i.e. the best places to locate the available facilities. Secondly, *what* size i.e. which is the best capacity to assign to the generic logistic facility. Thirdly, *when* i.e. with regard to a specific location, which periods of time demand a certain amount of production capacity. Recent studies on FL are presented by Snyder (2006), Keskin & Uster (2007) and Hinojosa et al. (2008). ReVelle et al. (2008) present a taxonomy of the broad field of facility location modelling.

Class of location problems/models	Description	Examples and references
Single facility minimum location problems	optimal location of a single facility designed to serve a pool of existing customers	see Francis et al. (1992)
Multiple facility location problems (MFLP)	optimal location of multiple facilities capable of serving the customers in the same or in different ways.	p-Median problem (p-MP), p-Centre problem (p-CP), uncapacitated facility location problem (UFLP), capacitated facility location problem (CFLP), quadratic assignment problem (QAP), and plant layout problem
Facility location allocation problem (LAP)	several facilities have to be located and flows between the new facilities and the existing facilities (i.e. demand points) have to be determined. The LAP is an MFLP with unknown allocation of demand to the available facilities.	see Love et al. (1988), Manzini et al. (2007a,b)
Network location problem (NLP)	a LAP where the network (routes, distances, travel times, etc.) have to be constructed and configured.	see Sule et al. (1988), Manzini et al. (2007b)
Extensions classes of NLP and LAP	Tours development problem. Vehicle routing problem (e.g. assignment procedures for the travelling salesman problem and the truck routing problem). Dynamic location models. Multi-period dynamic facility location problem. Integrated distribution network design problem (decisions regarding locations, allocation, routing and inventory).	see Sule et al. (1988), Ambrosino and Scutellà (2005), Gebennini et al. (2007), Manzini et al. (2007b).

Table 1. Main classes of facility locations in logistics.

3. A PDSD conceptual framework

Limited research has been carried out into solving the supply chain problems from a "system" point of view, where the purpose is to design an integrated model for supply chains. The authors propose an original conceptual framework which is illustrated in Fig.2 and is based on the integration of three different planning levels (Manzini et al. 2007b):

A. *Strategic planning.* This level refers to a long term planning horizon (e.g. 3-5 years) and to the strategic problem of designing and configuring a generic multi stage supply chain. Management decisions deal with the determination of the number of facilities, geographical locations, storage capacity, and allocation of customer demand (Manzini et al. 2006). The proposed supporting decisions approach to the strategic planning is based on a *static network design* as illustrated in Section 4.

B. *Tactical planning*. This level refers to both long and short term planning horizons and deals with the determination of the best fulfillment policies and material flows in a supply chain, modelled as a multi-echelon inventory distribution system. The proposed supporting decisions approach is specifically based on the application of *simulation* and *multi-scenario what-if analysis* as illustrated in Section 5.

C. *Operational planning.* It refers to long and short term planning horizons. In fact, the main limit of the modelling approach based on the static network design is based on the absence of time dependency for problem parameters and variables. A period *dynamic network design* differs from the static problem by introducing the variable time according to the determination of the number of logistic facilities, geographical locations, storage capacities, and daily allocation of customer demand to retailers (i.e. distribution centers or production plants). The very short planning horizon is typical of a logistic requirement planning (LRP), i.e. a tool comparable to the well-known material requirement planning (MRP) and capable of planning and managing the daily material flows throughout the logistic chain.

	Decisions	**Planning horizon**	**Unit period of time**	**Problem classification**	**Objective**	**Modeling & Supporting decision methods**
(A) **Strategic planning** Static Network **Design**	Number of facilities, locations, storage capacity, allocation of demand	long term e.g. 3-5 years	Single period (e.g. 3-5 years)	*Location allocation problem (LAP) & Network location problem (NLP)*	Network definition, cost minimization – profit maximization	Mixed integer programming
(B) **Tactical planning** Fulfillment system **Design & Management**	Lead time, service level (LS), safety stock (SS)	long term and/or short term (e.g. week, day)	Multi period (e.g. day)	*Multi-echelon inventory distribution fulfillment system*	Determination of fulfillment policies, material flow management, control of the bull-whip effect	Dynamic modeling & simulation
(C) **Operational planning (logistic requirement)** Dynamic Network **Management**	**(A)** + Allocation of demand of customers (*retailers*) to retailers (*distribution centers and/or production plants*)	short term	Multi period (e.g. day)	*Dynamic location allocation problem (LAP).*	Logistic requirement planning (LRP)	Mixed integer programming & simulation

Figure 2. Conceptual framework for the Production Distribution Logistic System Design problem

Next three sections presents effective models for approaching to the previously described planning levels for the optimization of a multi-echelon production distribution system.

4. Static network design

An effective mathematical formulation of the static (i.e. not time dependent) network design problem is based on the LAP (Manzini et al. 2006, 2007a, 2007b). The objective is to configure the distribution network by minimizing a cost function and maximizing profit. LAP belongs to the NP-hard complexity class of decision problems, and the generic occurrence requires the simultaneous determination of the number of logistic facilities (e.g. production plants, warehousing systems, and distribution centers), their locations, and the assignment of customer demand to them.
Fig. 3 exemplifies a distribution system whose configuration can be object of a LAP. The generic occurrence of a LAP is usually made of several entities (i.e. facilities). Fig. 4 illustrates an example of a worldwide distribution of a large number of customers within a company logistic network. In particular the generic dot represents a demand point and its colour is related to the amount of demand during a period of time T (e.g. one year). The colour of the geographic area relates to the average unit cost of transportation from a central depot located in Ohio.

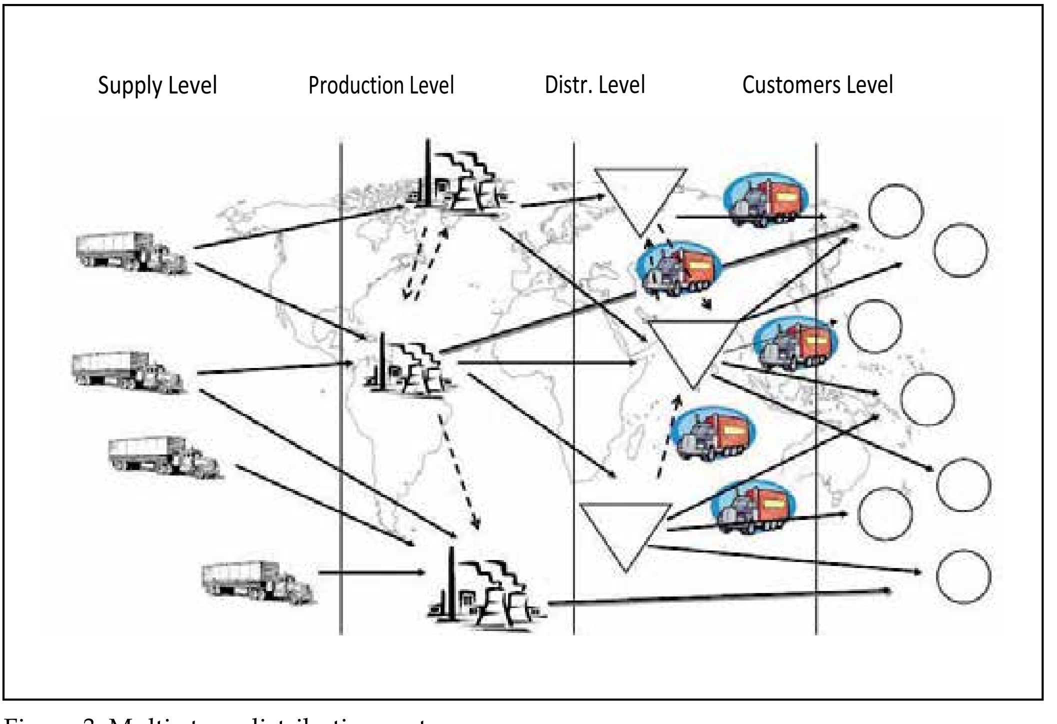


Figure 3. Multi-stage distribution system

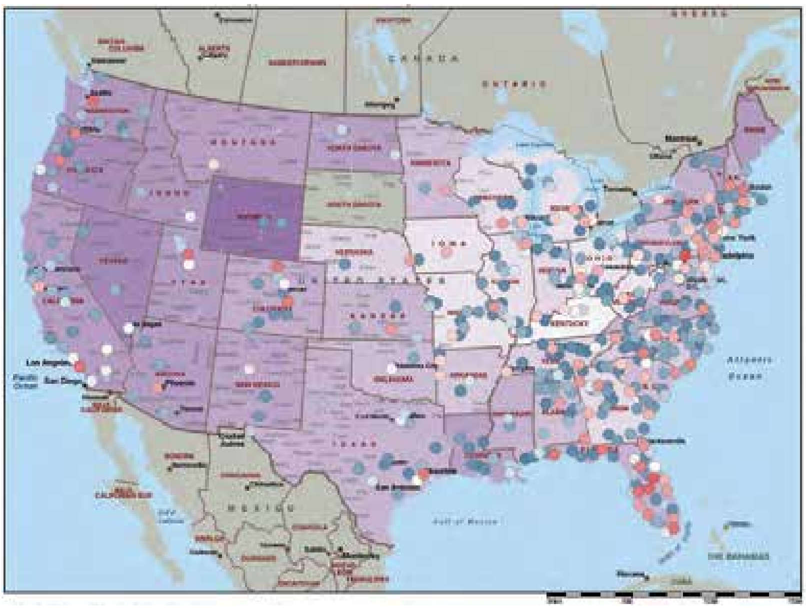


Figure 4. Exemplifying distribution of points of demand

4.1 Single commodity 2-stage model (SC2S)

The following static model has been developed by the authors for the design of a 2-stage logistic network which involves three different levels of facilities (i.e. types of nodes): a production plant which can be identified by a central distribution center (CDC), a set of regional distribution centers (RDCs), and a group of customers which represent the points of demand.

This model controls the distribution customers lead times (t_{kl} where k is a generic RDC and l is the generic demand point, i.e. customer) introducing a maximum admissible delivery delay, called $T_{R.}$ In particular it is possible to measure and optimize three different portions of customers demand:

1. part of demand delivered within lead time T_l (defined for customer l), i.e. $t_{kl} < T_l$;
2. part of demand not delivered within T_l but within the admissible delivery delay, i.e. $t_{kl} < T_l + T_R$;
3. part of demand not delivered because the delay is not admissible, i.e. $t_{kl} > T_l + T_R$.

The objective function is defined as follows:

$$\Phi_{SC2S} = \underbrace{\sum_{k=1}^{K} c'_k \, x'_k \, d'_k}_{C(CDC-RDC)} + \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} c'_{kl} \, x_{kl} d_{kl}}_{C(RDC-Demand)} +$$

$$+ \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} A(c_{kl} x_{kl}^{in} d_{kl})}_{C_{DELAY}} + \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} B x_{kl}^{out}}_{C_{UNDELIVERED}} + \underbrace{\sum_{k=1}^{K} (f_k z_k + v_k x'_k)}_{C_{RDC}} \tag{1}$$

The mixed integer linear model is:

$$\min\{\Phi_{SC2S}\}$$

subject to:

$$x'_k = \sum_{l=1}^{L}[x_{kl} + x_{kl}^{in} + x_{kl}^{out}] \tag{2}$$

$$\sum_{k=1}^{K}[x_{kl} + x_{kl}^{in} + x_{kl}^{out}] = D_l \tag{3}$$

$$\sum_{l=1}^{L} y_{kl} \le p z_k \tag{4}$$

$$\sum_{k=1}^{K} y_{kl} = 1 \tag{5}$$

$$x_{kl} + x_{kl}^{in} \le D_l y_{kl} \tag{6}$$

$$x_{kl} = 0 \quad if \quad t_{kl} > T_l \tag{7}$$

$$\left.\begin{array}{l} x_{kl}^{in} = 0 \\ y_{kl} = 0 \end{array}\right\} \quad if \quad t_{kl} > T_l + T_R \tag{8}$$

$$\begin{cases} x_{kl} \ge 0 \\ x_{kl}^{in} \ge 0 \\ x_{kl}^{out} \ge 0 \end{cases} \tag{9}$$

$$z_k, y_{kl} \in \{0,1\} \tag{10}$$

where

k = 1,..,K RDC belonging to the second level of the generic logistic network;
l = 1,..,L demand point belonging to the third level of the network;
c'_k transportation unit cost from the CDC to the RDC *k*;
x'_k product quantity from the CDC to the RDC *k*;
d'_k distance from the CDC to the RDC *k*;
c_{kl} transportation unit cost from the RDC *k* to the point of demand *l*;
x_{kl} product quantity from the RDC *k* to the point of demand *l*;
d_{kl} distance from the RDC *k* to the point of demand *l*;
x_{kl}^{in} product quantity delivered with an admissible delay from the RDC *k* to the point of demand *l*;

x_{kl}^{out} product quantity (from the RDC k to the point of demand l) not delivered because it does not respect the maximum admissible delay;
y_{kl} 1 if the RDC k supplies the point of demand l. 0 otherwise;
z_k 1 if the RDC k is selected by the solution of the problem; 0 otherwise;
f_k fixed cost to operate using the RDC k;
v_k variable cost (based on the product quantity flow) for the RDC k;
D_l demand from the point of demand l;
t_{kl} delivery time from the RDC k to the point of demand l;
T_l delivery time required by the point of demand l;
p maximum number of points of demand supplied by a generic RDC;
A additional delivery unit cost for product delivered with an admissible delay;
B penalty unit cost for units of product not delivered because they do not respect the admissible delay;
T_R admissible delivery delay.

The objective function is composed of five different addends:

1. *C(CDC-RDC).* It is the global transportation cost from the first level (CDC) to second level (RDCs);
2. *C(RDC-Demand).* It is the global transportation cost from the second level to the third level (points of demands);
3. *C(DELAY*). It measures the cost for the product quantities in delivery delay but delivered during admissible delay time T_R;
4. *C(UNDELIVERED).* It is a penalty cost associated with product quantities (from the RDCs to the points of demand) not delivered because they failed to respect the delay time T_R;
5. *C(RDC).* It is the cost associated with the management of the set of RDCs.

4.2 Single commodity 3-stage model (SC3S)

The previously described mixed integer programming model has also been modified in order to take into account the product levels and related flows and costs, which were previously neglected. The following presents the adopted objective function which quantifies also the transportation cost from the production level to the CDC.

$$\Phi_{SC3S} = \underbrace{\sum_{i=1}^{I}\sum_{j=1}^{J} c''_{ij}\, x''_{ij}\, d''_{ij}}_{C(PRODUCTION-CDC)} + \underbrace{\sum_{j=1}^{J}\sum_{k=1}^{K} c'_{jk}\, x'_{jk}\, d'_{jk}}_{C(CDC-RDC)} + \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} c_{kl} x_{kl} d_{kl}}_{C(RDC-Demand)} +$$
$$+ \underbrace{\sum_{j=1}^{J}[f_j w_j + v_j \sum_{i=1}^{I} x''_{ij}]}_{C_{CDC}} + \underbrace{\sum_{k=1}^{K}[f_k z_k + v_k \sum_{j=1}^{J} x'_{jk}]}_{C_{RDC}} +$$
$$+ \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} A c_{kl} x_{kl}^{in} d_{kl}}_{C_{DELAY}} + \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L} B x_{kl}^{out}}_{C_{UNDELIVERED}} \tag{11}$$

The new set of constraints introduced by this model have now been omitted because they are very similar to those previously discussed.
New symbols introduced by this model are:

i = 1,..I production plant;
j = 1,..,J central distribution center CDC;
c''_{ij} transportation unit cost from the production plant *i* to the CDC *j*;
x''_{ij} product quantity from the production plant *i* to the CDC *j*;
d''_{ij} distance from the production plant *i* to the CDC *j*;
c'_{jk} transportation unit cost from the CDC *j* to the RDC *k*;
x'_{jk} product quantity from the CDC *j* to the RDC *k*;
d'_{jk} distance from the CDC *j* to the RDC *k*;
f_j fixed operating cost using the CDC *j*;
v_j variable cost (based on the product quantity flow) for the CDC *j*;
w_j *1* if the CDC *j* is selected by the solution of the problem; *0* otherwise.

The following new addends have been introduced into the objective function:

6. *C(PRODUCTION-CDC)*. It represents the global cost for the distribution of products from the first level to the CDCs level;
7. C_{CDC} measures the cost associated with the management of the set of CDCs.

4.3 Multi commodity 3-stage model (MC3S)

This model differs from previously illustrated because it is a multi commodity model: several different products can be simultaneously involved for supporting strategic decisions on network configuration. The objective function is:

$$
\begin{aligned}
\Phi_{MC3S} == & \underbrace{\sum_{M=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J} c''_{mij}\, x''_{mij}\, d''_{mij}}_{C(PRODUCTION-CDC)} + \underbrace{\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{k=1}^{K} c'_{mjk}\, x'_{mjk}\, d'_{mjk}}_{C(CDC-RDC)} + \\
& + \underbrace{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{L} c_{mkl} x_{mkl} d_{mkl}}_{C(RDC-Demand)} + \underbrace{\sum_{j=1}^{J}[f_j w_j + v_j \sum_{m=1}^{M}\sum_{i=1}^{I} x''_{mij}]}_{C_{CDC}} + \underbrace{\sum_{k=1}^{K}[f_k z_k + v_k \sum_{m=1}^{M}\sum_{j=1}^{J} x'_{mjk}]}_{C_{RDC}} + \\
& + \underbrace{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{L} A c_{mkl} x^{in}_{mkl} d_{mkl}}_{C_{DELAY}} + \underbrace{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{l=1}^{L} B x^{out}_{mkl}}_{C_{UNDELIVERED}}
\end{aligned}
\tag{12}
$$

New symbols introduced by this model are:

m = 1,..,M product family;
c''_{mij} transportation unit cost from the production plant i to the CDC j for the family m;
x''_{mij} product quantity from the production plant i to the CDC j for the family m;
d''_{mij} distance from the production plant i to the CDC j for the family m;
c'_{mjk}, x'_{mjk}, d'_{mjk}, c_{mkl}, x_{mkl}, d_{mkl}, etc. are similar to c'_{jk}, x'_{jk}, d'_{jk}, c_{kl}, x_{kl}, d_{kl}, etc., which were introduced in the previous objective function (12), but they refer to the generic family of products *m*.

4.4 Strategic planning. Case study

This section presents the results obtained by the application of previously illustrated mixed integer linear location allocation models to the rationalization and optimization of the logistic network for the distribution of components in a leading electronics Italian company (this case study is deeply presented in Manzini et al. 2006).

Figure 5 illustrates the network configuration made of 4 levels (production level, central DC level, RDC level and customer level) and 3 stages (production plants-CDC, CDC-RDCs and RDCs-Customers). The model does not consider multiple periods of time according to a long-term strategic design and planning of the network.

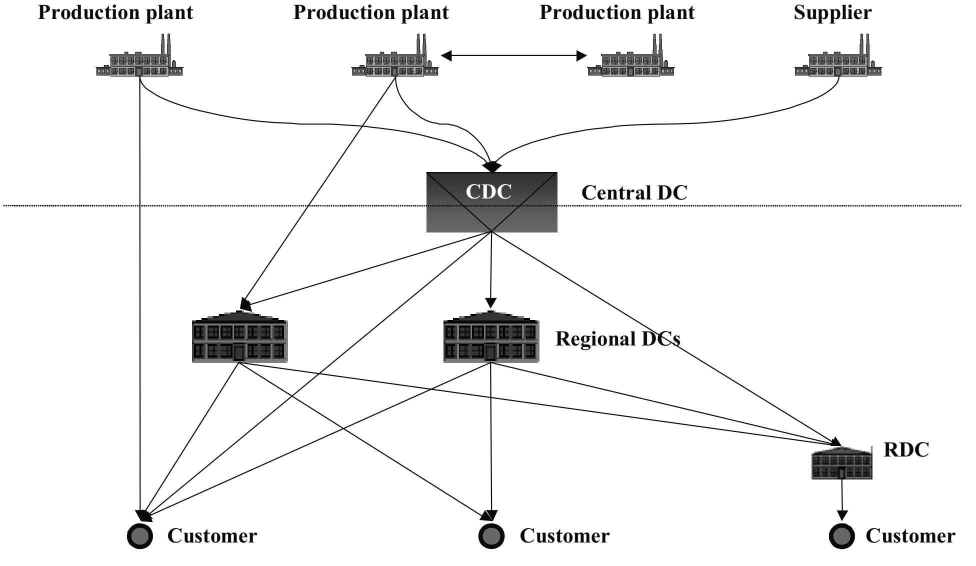


Figure 5. Strategic planning. Network configuration in the case study

The products number several thousands and their demand is strongly fragmented; nevertheless in a first approximation the products' mix has been reduced to a single product according to types of products which are very small and so similar that their individual quantities are unimportant. Then the model of the system does not consider multiple periods of time according to a long-term strategic design and planning. Furthermore this aggregated demand of products assumes a constant trend during a year. Finally more than 90% of the delivered products passed and passes through the CDC. As a consequence the flow of products along the system can be simply measured in tons and for the system design and optimization it is possible to apply the single commodity models illustrated above by omitting the production level in the SC2S model. Fig.6 presents the location of a pool of DCs and a set of exemplifying points of demand according to the projection of longitude and latitude values into Cartesian coordinates, useful for the determination of the distance between two generic locations.

The model illustrated in Section 4.1 has been applied to optimize the so-called "actual" network (i.e. to minimize the global logistic cost function in the original configuration of the system, also called "AS-IS", before the optimization study) for different values of T_R. Fig.7 presents the actual/AS-IS configuration of the system, which is compared with the best system configuration obtained by the application of the linear model when T_R is equal to 0. Fig.8 presents the results obtained when T_R is optimized (the optimal value is 9). Finally Fig.9 compares the actual configuration of the network with the best one distinguishing the different kinds of logistic costs of objective function (1): the global cost reduction is approximately 4.22% (about € 200000 per year) of the actual annual cost.

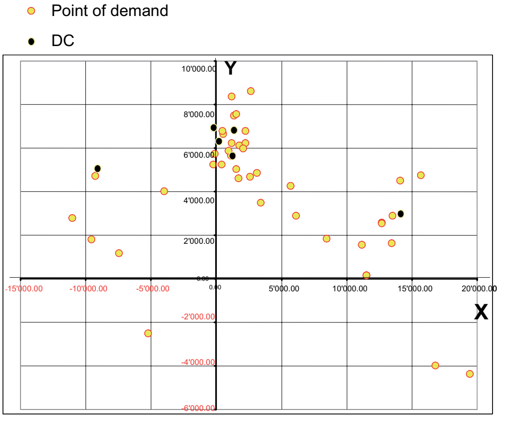


Figure 6. Points of demand and DCs in Cartesian coordinates

a) Actual configuration (5 DCs + CDC) *b) Best Configuration (3 DCs + CDC)*

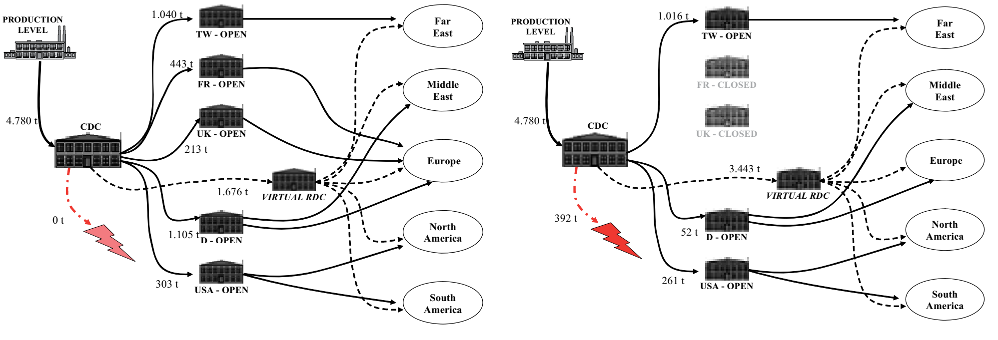


Figure 7. a) Actual configuration, b) Best configuration when TR=0

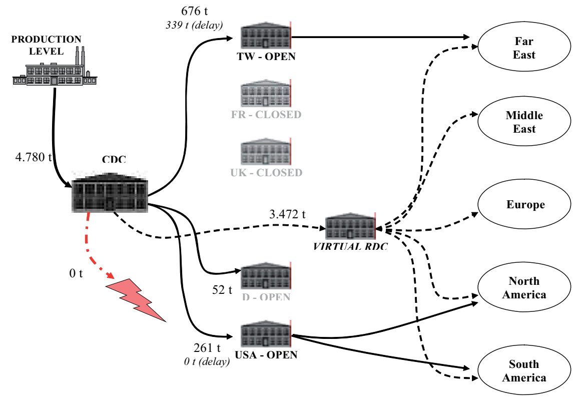


Figure 8. Best configuration when TR=9

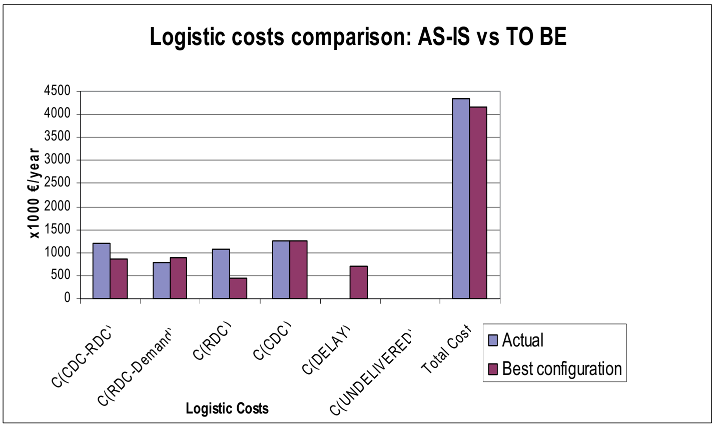


Figure 9. Logistic costs comparison AS-IS vs best configuration.

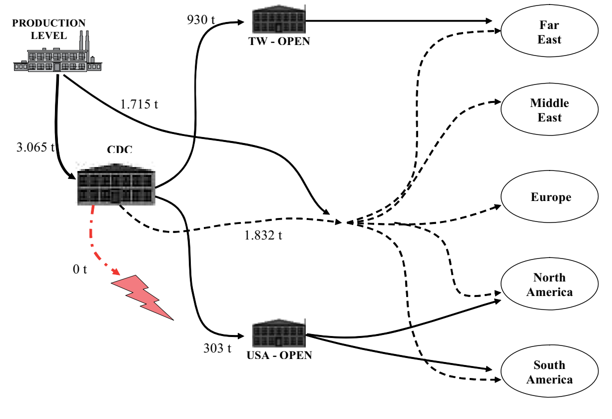


Figure 10. SC3S solution, when TR=9

Fig.10 shows the solution to the SC3S problem found by the linear programming solver MPL (Mathematical Programming Language by Maximal Software Inc.) introducing the production level. This solution cannot be compared directly with the solution produced by the SC2S because the second one does not quantify transportation costs from the production level. In particular, the opportunity to supply products directly from the production level to the point of demand strongly reduces the storage quantities located in the CDC. This opportunity is modelled by the introduction of a virtual DC (virtual RDC in figures 7 and 8).
The previously illustrated multi-commodity model (the MC3L) is capable of distinguishing and quantifying the flows of different product families. By applying the model to the case study where M = 9, I = 7, J = 8, K = 13 and L = 351, the solution presented in fig. 11 is obtained. It is based on 3 DCs:

i. a "virtual DC" through which products flow virtually and directly from production level to customers' level;
ii. a CDC, which is capable of supplying customer demand directly (e.g. Europe) through the "virtual RDC";
iii. 2 RDCs: TW supplies the Far East, while USA supplies North and South America.

This result shows that the MC3L model is effective for rapid strategic and long-term design of a complex logistic network.

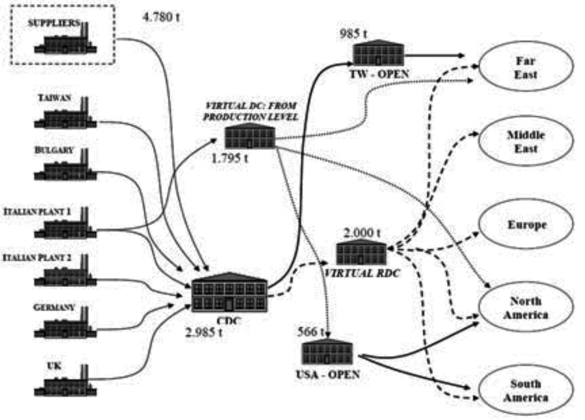


Figure 11. Multi-commodity model

5. Fulfillment system design

Being strategic and tactical, this level refers to both long and short term planning horizons. Therefore, the solution to the problem deals with the determination of the best fulfillment policies and material flows in a SC, modelled as a multi-echelon inventory distribution system. The decisional approach is specifically based on the application of simulation and multi-scenario what-if analysis.
The literature largely discusses the application of simulation and stochastic modelling to support the design and management of SCs (Chan & Chan 2005, 2006, Manzini et al. 2005b, Ng et al. 2003, Santoso et al. 2005). Simulation can model complex real systems incorporating many non-deterministic factors, such as uncertainty in demand, lead times,

number of facility locations, assignment of customer demand, etc. In particular, thanks to a what-if approach, simulation models can provide a thorough understanding of the dynamic behaviours of a system as well as assisting evaluation of different operational strategies.
The modelling approach of this planning level is dynamic, i.e. multi-period. So the modelled unit period of time can be the day. Every actor in the chain is modelled as a dynamic entity whose behaviour is deterministic or stochastic.
By using the dynamic modelling of the distribution system, management can implement different fulfillment strategies. In particular, the reorder strategy for the generic stock point (i.e. facility) of the distribution network can be either push or pull, e.g. a supplier can push materials to a distribution center which supplies retailers in accordance to a pull or push strategy.

5.1 Case study. A multi-echelon 3-stage system

Fig.12 exemplifies a 3-stage divergent system where each stockpoint has a unique supplier but it may deliver material to multiple other stockpoints. In particular stockpoint *0* is supplied by several external sources (e.g. production facilities), and the "end stockpoints" are the entities that deliver materials directly to final customers (whose demand can be stochastic). All products are supplied via the network in order to satisfy customer demand.
Fig.13 illustrates the well known reorder policy usually adopted for the determination of the reorder quantity of a retailer (or a DC) in a period of time t_i. This quantity is defined by the following equation:

$$q_i = S - I(t_i) \tag{13}$$

where

t_i i^{th} reviewing period (i.e. unit period of time);

$I(t_i)$ on-hand inventory in time t_i;

t_l identifies the variable lead time of the generic replenishment (Fig.13).

This is the order-up-to *(S,s)* replenishment policy whose several contributions in the literature confirm its effectiveness because it is a parametric rule which can be easily applied to represent different fulfillment policies such as the periodic review rule, the fixed order quantity rule, the economic order quantity (EOQ), etc.

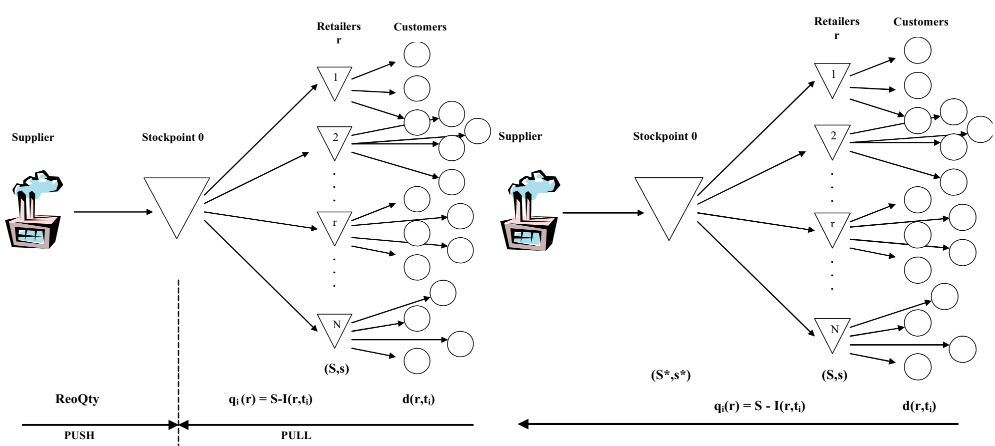


Figure 12. A 3-stage divergent system. *Push-pull* vs *pull-pull* strategies

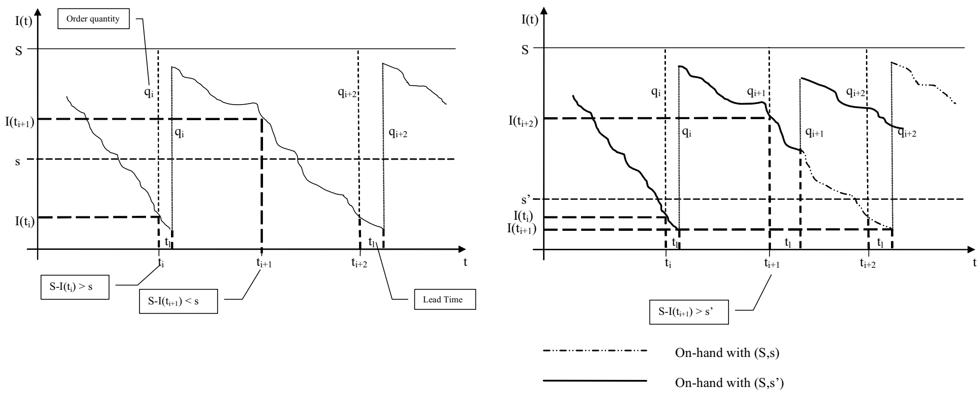


Figure 13. (S,s) policy. s'<s

The following figures present some of the results obtained from a what-if analysis conducted on the simulation of several hypothetical scenarios in order to identify some effective guidelines for designing new Demand/Supply Chain. These results also illustrate the application of some statistical techniques to the management of the performance data in accordance with the proposed framework previously illustrated. In particular, Fig.14 presents the trend of some performance indexes (*LS_1, LSCent, LStot*, etc.) introduced to support the validation of a fulfillment model by identifying the warm-up period (equal to 500 time periods) and the right number of repetitions (equal to 10 and in agreement with a confidence interval equal to 0.95) for each simulation run. More details are reported in Manzini et al. (2005a).

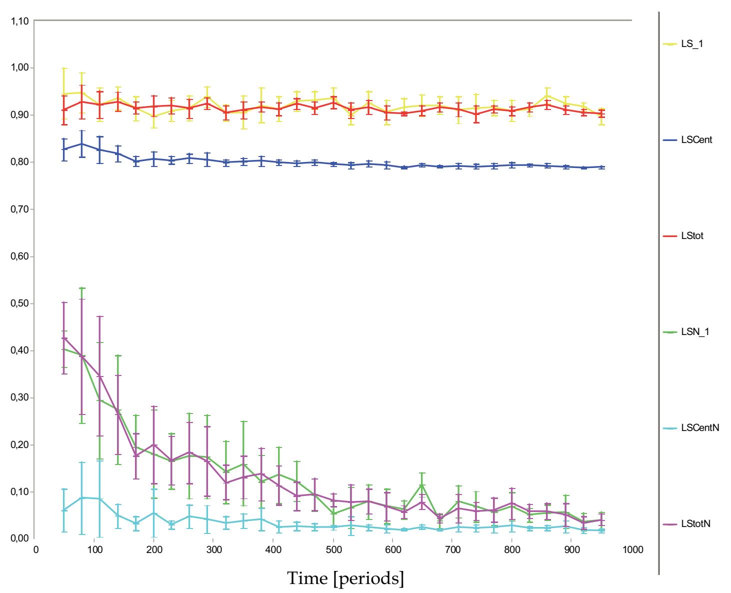


Figure 14. Validation analysis. Warm-up periods

Fig.15 illustrates the results of a factorial analysis (in particular an ANOVA analysis) for an exemplifying performance index *Perf1(r=1,T=500)* defined as follows:

$$Perf1(r,T) = \frac{LS_1(r,T)}{CUni1_r(T)} \tag{14}$$

where

r	retailer;
T	planning period;
$LS_1(r,T)$	retailer service level , defined as the ratio between the whole amount of quantity delivered *S(r,T)* and the total amount of demand *D(r,T)* from all customers to *r;*
$CUni1_r(T)$	retailer unit cost.

In particular the retailer unit cost is defined as the ratio between the global cost for the retailer and the global economic value of the requested demand:

$$CUni1_r(T) = \frac{Ctot_r(T)}{\sum_{t_i} d(r,t_i) \cdot Unit\,Price_r} \tag{15}$$

where

$Ctot_r(T)$	global cost for the retailer in period *T;*
$d(r,t_i)$	customers demand in unit period of time t_i for retailer *r;*
$Unit\,Price_r$	price of product for retailer *r*.

As a consequence the value of *Perf1(r=1,T=500)* measures the relationship between the generic service level (defined for a retailer-r) and the related logistic unit cost.

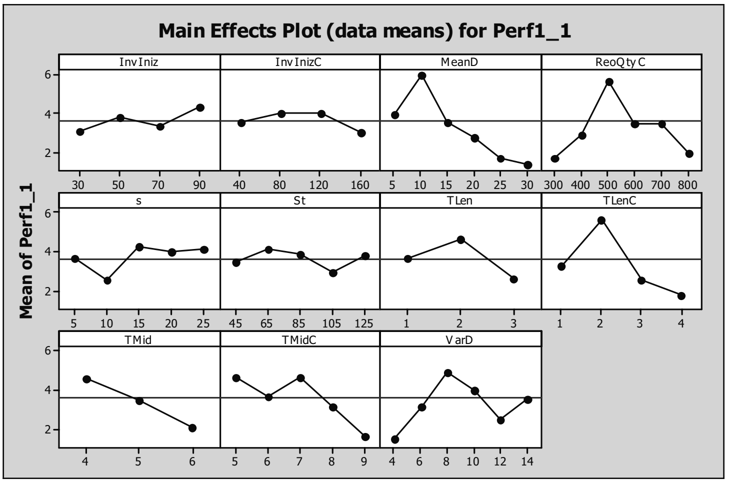


Figure 15. ANOVA Analysis.

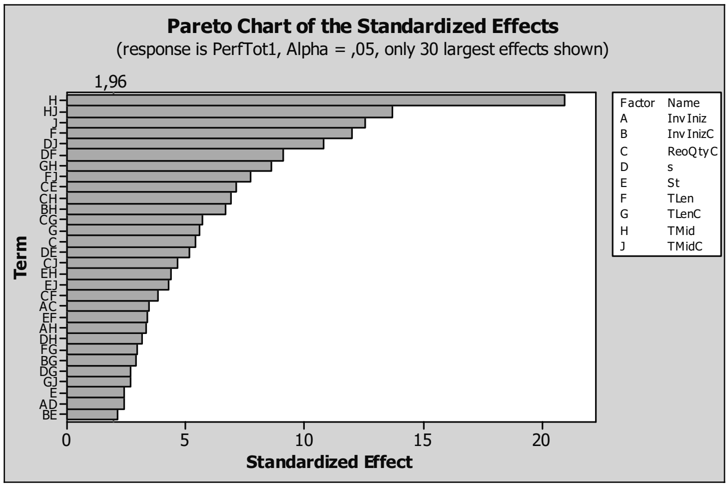


Figure 16. Pareto chart of the standardized effects

By the multi-level factorial analysis it is possible to identify the existence of significant increasing/decreasing (or decreasing/increasing) trends, the existence of optimal values and combinations of values for system performance optimization. Fig. 16 illustrates the Pareto Chart of the Standardized effects obtained by a 2^K factorial analysis conducted on another performance index. The collection of several campaigns of factorial analysis support the identification of the most critical factors and combinations of factors affecting the system performance.

6. Network management and dynamic facility location

This planning level is simultaneously both tactical and operational, and refers to long and short term planning horizons. In fact, the main limit of the modelling approach based on the static LAP is based on the absence of time dependency for problem parameters and variables. The multi-period dynamic LAP differs from the static problem by introducing the variable time according to the determination of the number of logistic facilities, geographical locations, storage capacities, and daily allocation of customer demand to retailers (i.e. distribution centers or production plants). The very short planning horizon is typical of a logistic requirement planning (LRP), i.e. a tool comparable to the well-known material requirement planning (MRP) and capable of planning and managing the daily material flows throughout the logistic chain.

6.1 Multi period single commodity 2-stage model (SCMP2S)

An original and illustrative mathematical formulation of the dynamic LAP has recently been developed by Manzini et al. (2007a) and is now discussed: it is a multi period single commodity two stages (SCMP2S) linear model based on the application of mixed integer programming. The logistic network is composed of two stages that involve the levels introduced and discussed in section 3.1. The cost-based objective function Φ_{SCMP2S} is:

$$\Phi_{SCMP2S} = \underbrace{\sum_{k=1}^{K}\left(c'_k d'_k \sum_{t=1}^{T} x'_{kt}\right)}_{C(CDC-RDC)} + \underbrace{\sum_{k=1}^{K}\sum_{l=1}^{L}\left[c_{kl} d_{kl} \sum_{t=1}^{T}\left(x_{klt} + x_{klt}^{delay}\right)\right]}_{C(RDC-Demand)+C_{DELAY}} + \underbrace{\sum_{k=1}^{K}\sum_{t=1}^{T} c^p x'_{kt}}_{C_{PROD}} + \underbrace{\sum_{k=1}^{K}\sum_{t=1}^{T} c^s I_{kt}}_{C_{STORAGE}} +$$

$$+ \underbrace{\sum_{k=1}^{K} f_k z_k + \sum_{k=1}^{K}\sum_{t=1}^{T} v_k x'_{kt}}_{C_{RDC}} + \underbrace{W \cdot \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T} S_{klt}}_{C_{STOCK-OUT}} \tag{16}$$

The linear model is :

$$\min\left\{\Phi_{SCMP2S}\right\}$$

subject to

$$P_t \le C_t^P \tag{17}$$

$$P_{t-lt^{prod}} = \sum_{k=1}^{K} x'_{kt} \tag{18}$$

$$I_{k,t-1} - I_{k,t} + x'_{k,t-t_k^{deliv}} = \sum_{l=1}^{L} x_{klt} + \sum_{l=1}^{L} S_{kl,t-1} \tag{19}$$

$$I_{kt} \le D_{tot} \cdot z_k \tag{20}$$

$$x_{klt} + S_{klt} = D_{l,(t+t_{kl}^{ev})} y_{kl,(t+t_{kl}^{ev})} \tag{21}$$

$$x_{klt}^{delay} = S_{kl,t-1} \tag{22}$$

$$\sum_{l=1}^{L} x_{klt}^{delay} \le D_{tot} \cdot z_k \tag{23}$$

$$\sum_{l=1}^{L} y_{klt} \le p \cdot z_k \tag{24}$$

$$\sum_{k=1}^{K} y_{klt} = 1 \cdot D_{kl}^{NNull} \tag{25}$$

$$t_{kl}^{ev} y_{klt} \le T_l \tag{26}$$

$$I_{k0} = I_k^{begin} \tag{27}$$

$$S_{kl0} = S_{kl}^{begin} \tag{28}$$

$$S_{klT} = 0 \tag{29}$$

$$x_{klt} \geq 0 \tag{30}$$

$$x'_{kt} \geq 0 \tag{31}$$

$$S_{klt} \geq 0 \tag{32}$$

$$I_{kt} \geq 0 \tag{33}$$

$$z_k, y_{klt} \in \{0,1\} \tag{34}$$

where

$k = 1,...,K$ RDC belonging to the second level of the logistic network;
$l = 1,...,L$ demand point belonging to the third level of the network;
$t = 1,...,T$ unit period of time along the planning horizon *T*;
x'_{kt} product quantity from the CDC to the RDC *k* in *t*;
x_{klt} on time delivery quantity i.e. product quantity from the RDC *k* to the point of demand *l* in *t*;
S_{klt} product quantity not delivered from the RDC *k* to the point of demand *l* in *t*. The admissible period of delay is one unit of time: consequently, this quantity must be delivered in the period *t* + 1;
x_{klt}^{delay} delayed product quantity delivered late from the RDC *k* to the point of demand *l* in *t*. The value of this variable corresponds to $S_{kl,t-1}$;
I_{kt} storage quantity in the RDC *k* at the end of the period *t*;
P_t production quantity in time period *t*. It is available after the lead time lt^{prod};
y_{klt} 1 if the RDC *k* supplies the point of demand *l* in *t*. 0 otherwise;
z_k 1 if the RDC *k* belongs to the distribution network. 0 otherwise;
c'_k unit cost of transportation from the CDC to the RDC *k*;
d'_k distance from the CDC to the RDC *k*;
c_{kl} unit cost of transportation from the RDC *k* to the point of demand *l*;
d_{kl} distance from the RDC *k* to the point of demand *l*;
W additional unit cost of stock-out;
c^p unit production cost;
c^s unit inventory cost which refers to *t*. If *t* is one week, the cost is the weekly unit storage cost;
f_k fixed operative cost of the RCD *k*;

v_k variable unit (i.e. for each unit of product) cost based on the product quantity which flows through the RDC k;

D_{lt} demand from the point of demand l in the time period t;

S_{kl}^{begin} starting stock-out at the beginning (t = 0) of the horizon of time T;

I_k^{begin} starting storage quantity in RDC k;

p maximum number of points of demand supplied by a generic RDC in any time period;

$D_{tot} = \sum_{l=1}^{L}\sum_{t=1}^{T} D_{lt}$ total amount of customer demand during the planning horizon T;

C_t^P production capacity available in t;

D_{lt}^{NNull} 1 if demand from the customer l in t is not null. 0 otherwise;

T_l delivery time required by the point of demand l;

lt^{prod} production lead time;

t_k^{deliv} delivery lead time from the CDC to the generic RDC k;

t_{kl}^{ev} delivery lead time from the RDC k to the point of demand l.

The objective function is composed of various contributions:

1. *C(CDC-RDC).* It measures the total cost of transportation from the first level (CDC) to the second level (RDCs);
2. *C(RDC-Demand)*, i.e. the total cost of transportation from the second level (RDCs) to the third level (points of demand);
3. C_{PROD}, i.e. the total production cost;
4. $C_{STORAGE}$, i.e. the total storage cost;
5. C_{RDC}, first addend: total amount of fixed costs for the available RDCs;
6. C_{RDC}, second addend: total amount of variable costs for the available RDCs;
7. $C_{STOCK\text{-}OUT}$, i.e. the total amount of extra stock-out cost. The parameter W is a large number so that solutions capable of respecting the customer delivery due dates can be proposed.

The more significant constraints are expounded as follows:

- (19) guarantees the conservation of logistic flows to each facility in each period of time t;
- (21) states that the product quantity from the RDC k to the point of demand l is delivered according to a lead time t_{kl}^{ev} in order to satisfy the demand of period $t + t_{kl}^{ev}$. Stock-outs are backlogged and supplied in the following period;
- (25) guarantees the individual sourcing requirement: if the demand of node l in t is not null (D_{lt}^{NNull} = 1), only one RDC must serve the point of demand l ; otherwise (D_{lt}^{NNull} = 0) the point of demand l is not assigned to any facilities;
- (26) ensures that a demand node is only assigned to an RDC if it is possible to carry out the order by the customer delivery due date.

The result of this problem formulation is explained in Fig. 2 (*Decisions* section): daily allocation of logistic requirements, i.e. determination of number of facilities, locations, storage capacities, and allocation of demand of customers (retailers) to retailers (DCs and/or production plants).

6.2 Multi-period model with safety stock optimization

The following model extends and improves the previous one by including the optimization of safety stock (SS) at each facility that belongs to the logistic network. The SS is the minimal level of inventory (storage quantity) that a company seeks to have on hand at any unit of time t in accordance to the uncertainty of customer demand. In particular the SS level depends on the following main factors (Persona et al., 2007):

- customer service level. High levels ask for great quantities of SS levels;
- number and locations of points of demand which are allocated to production/distribution facilities;
- variance of demand at each facility.

The proposed model do not consider deterministic values of customer demand and this choice strongly increases the complexity of the decision problem. In particular, a recursive solving procedure has been properly developed and illustrated by Gebennini et al. (2007).

The new problem formulation is based on a non-linear analytical model capable of optimizing the SS levels within the distribution system, utilizing the notation introduced for the SCMP2S and in the following lines:

θ_{kl} assumes value 1 if the RDC k supplies the point of demand l in any unit time t which belongs to T. 0 otherwise;

σ_l^2 variance of demand at the point of demand l;

$\hat{k}$ safety factor to control customer service level;

$\hat{\sigma}_{kl} = t_{kl}^{ev} \cdot \sigma_l$ combined variance at the RDC k serving the point of demand l.

The proposed analytical model of LAP with safety stock is:

$$Min \sum_{k=1}^{K}\left(c_k^{'}d_k^{'}\sum_{t=1}^{T}x_{kt}^{'}\right)+\sum_{k=1}^{K}\sum_{l=1}^{L}\left[c_{kl}d_{kl}\sum_{t=1}^{T}\left(x_{klt}+x_{klt}^{delay}\right)\right]+\sum_{k=1}^{K}\sum_{t=1}^{T}c^{p}x_{kt}^{'}+$$

$$+\sum_{k=1}^{K}\sum_{t=1}^{T}c^{s}I_{kt}+\sum_{k=1}^{K}f_k z_k+\sum_{k=1}^{K}\sum_{t=1}^{T}v_k x_{kt}^{'}+\sum_{k=1}^{K}c^{s}\cdot\hat{k}\sqrt{\sum_{l=1}^{L}\sigma_{kl}^{2}\cdot\theta_{kl}}+W\cdot\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T}S_{klt} \tag{35}$$

subject to:

$$P_t \leq C_t^P \tag{36}$$

$$P_{t-1t^{prod}} = \sum_{k=1}^{K}x_{kt}' \tag{37}$$

$$I_{k,t-1}-I_{k,t}+x_{k,t-t_k^{deliv}}^{'} = \sum_{l=1}^{L}x_{klt}+\sum_{l=1}^{L}S_{kl,t-1} \tag{38}$$

$$I_{kt} \leq D_{tot}\cdot z_k \tag{39}$$

$$x_{klt} + S_{klt} = D_{l,(t+t_{kl}^{ev})} y_{kl,(t+t_{kl}^{ev})} \tag{40}$$

$$x_{klt}^{delay} = S_{kl,t-1} \tag{41}$$

$$\sum_{l=1}^{L} x_{klt}^{delay} \leq D_{tot} \cdot z_k \tag{42}$$

$$\sum_{l=1}^{L} y_{klt} \leq p \cdot z_k \tag{43}$$

$$\sum_{k=1}^{K} y_{klt} = 1 \cdot D_{kl}^{NNull} \tag{44}$$

$$t_{kl}^{ev} y_{klt} \leq T_l \tag{45}$$

$$\sum_{t=1}^{T} y_{klt} \leq \theta_{kl} \cdot T \tag{46}$$

$$I_{k0} = I_k^{begin} \tag{47}$$

$$S_{kl0} = S_{kl}^{begin} \tag{48}$$

$$S_{klT} = 0 \tag{49}$$

$$x_{klt} \geq 0, x'_{kt} \geq 0 \tag{50}$$

$$x_{klt}^{delay} \geq 0 \tag{51}$$

$$S_{klt} \geq 0 \tag{52}$$

$$I_{kt} \geq 0 \tag{53}$$

$$z_k, y_{klt}, Q_{kl} \in \{0,1\} \tag{54}$$

The objective function (35) minimizes the total network costs, composed of different contributions: transportation cost from the CDC to the RDCs, transportation cost from the RDCs to the points of demand, total production cost, total inventory cost including safety stock costs, fixed and variable costs associated respectively with the location of new facilities and with their working, and finally the total amount of extra stock-out cost.

Eq. (35) includes a non-linear term which represents the SS cost for the generic facility k in accordance with the following equation which quantifies a contribution to the determination of the variance of demand cumulated in k and generated by the customer l:

$$\hat{\sigma}_{kl}^2 = t_{kl}^{ev} \cdot \sigma_l^2 \tag{55}$$

Gebennini et al. (2007) illustrate a recursive procedure based on a linearization of Eq. (35) for the determination of an admissible solution to the non-linear model.

6.3 Case study. Multi-period model with SS

The proposed model illustrated in Section 6.2 has been applied to the optimization of the logistic network of the Italian electronics company object of the case study introduced in Section 4. A first scenario of interest, called AS-IS, refers to the availability of the whole set of actual RDCs. It has been used for a comparison with new network configurations based on the optimization of the logistic system (TO-BE scenario).

The obtained optimal solution establishes strategic and operational results such as the number and configuration of RDCs to keep open and the allocation of customer requests to the available RDCs. It is made up of only three RDCs: in Taiwan, USA and Germany. Direct shipments from the CDC to customers are suggested: South Europe, Middle East, North Africa are served directly from Italy. The allocation of demand to each RDC affects the SS levels that depend on both the total demand variance and the service level the company wants to guarantee. Table 2 presents the SS level maintained at each RDC which belongs to the network in the obtained solution: scenarios AS-IS and TO-BE are compared and a

Safety Stock [tons]			
RDC	**AS-IS**	**TO-BE**	**Δ%**
Dummy	19	26,5	39%
USA	6,9	6,6	-4%
FR	6,1	closed	-
UK	3,3	closed	-
D	9,7	1,7	-82%
TW	9,1	8,7	-4%
Total SS	**54,1**	**43,6**	**-19%**

Table 2. Safety stock level for RDCs

reduction of the total amount of SSs is achieved by the application of the optimizing procedure. Other tactical results obtained for each time period within the planning horizon T concern the product flows between CDC and RDCs, the product flows between RDCs and points of demand, the operational inventory levels and the production levels.

Table 3 presents the cost savings obtained by the reduction of the number of RDCs in accordance to the TO-BE system configuration. In particular the obtained savings do not affect negatively the customer service level that is supposed to be constant: the value of $\hat{k}$ is assumed equal to 2 (i.e. the customer service level is 0.95).

Costs of logistics	Δ %
Transportation cost (CDC-RDCs)	-48%
Transportation cost (RDCs-points of demand)	34%
Total transportation cost	**-9%**
Cost of RDCs	**-44%**
Inventory holding cost	**-19%**
Safety stock cost	**-19%**
Total cost of logistics	***-11%***

Table 3. Logistic cost comparison: AS-IS vs TO-BE

Finally Table 4 presents the percentage of variation in all the cost terms of the objective function (except for the production cost, unchanged in all simulated scenarios) by passing from $\hat{k}=1$ to $\hat{k}=3$, i.e. by incrementing the customer service level, in case of an higher unit inventory cost that makes total inventory holding cost more significant (total inventory holding cost is now 11% of transportation cost if $\hat{k}=1$, and 21% if $\hat{k}=3$).

Costs of logistics	Δ %
Transportation cost (CDC-RDCs)	2.0%
Transportation cost (RDCs-points of demand)	-0.3%
Total transportation cost	**0.3%**
Cost of RDCs	**0.0%**
Inventory holding cost	**95.9%**
Safety stock cost	**200.0%**
Total cost of logistics	***10.7%***

Table 4. Logistic costs variations when $\hat{k}$ passes from 1 to 3.

7. Conclusions and further research

This chapter presents original analytical models and supporting decision tools for the optimization of multi-echelon production distribution systems. In particular strategic models and methods have been discussed, applied and compared to tactical and operational approaches and applications. Nowadays industrial and service companies need effective and reliable supporting decision tools for the rapid planning, design, and execution of new production system from a strategic, tactical and operational point of view.

The literature continuously presents original models for product, process, and system design but these models are rarely based on integrated and system-oriented approaches, so future studies need to integrate simultaneous contributions from industrial management, OR, statistics, and IT sciences.

The size of the generic problem rapidly exceeds the computational limits of problem mathematical formulations and the need for local optimization decisions needs to be bypassed by using a reliable, efficient and global cost-based solutions that could be effective for the whole system. For this purpose Manzini et al. (2007b) introduce a supporting decision platform for the simultaneous design and management of a SC system (i.e. a production distribution network). The proposed platform represents the first step towards developing an expert system capable of supporting the integration of planning, design, management, control and optimization activities in a flexible production distribution system. The proposed tool is composed of strongly interrelated different decision modules. They are based on the application of both optimal mathematical formulations and simulation modelling which are capable of considering stochastic production and distribution processes such as transportation, logistic costing, customer demand, etc.

Further research is needed to develop supporting methodologies for the simultaneous design of products, process, and production distribution systems. How can the global economic impact of the introduction of a new product, a process (e.g. a manufacturing or an assembly technology) or a production system (e.g. flexible manufacturing system) be measured?

Furthermore industrial applications are achieved because the well known computational experiments proposed by several optimal or heuristic approaches in the literature suffer from the limitation of not being comprehensive and/or being unrealistic.

In particular further research on SC and production system planning should follow the direction traced by the development of ERP systems e.g. by providing more affective planning and optimization modules for multi-echelon production/distribution systems.

Finally, further research could take place to develop and apply supporting decision models capable of considering product recovery activities for the purpose of recycling, re-manufacturing, and reuse. These activities are an integral part of reverse logistics and management of product returns. In fact, scarce attention has been paid to how SC decisions and actions will affect other aspects of human life, such as the environment, social justice, and sustainability of natural resources.

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16

Concurrent Design of Product Modules Structure and Global Supply Chain Configuration

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1. Introduction

In globally distributed supply chains, the classical logistics decisions of facilities location, sourcing and distribution are greatly influenced by political and economic factors. The fierce competition, fluctuations in currency values, intellectual property considerations and international trade agreements, tariffs and laws and government's tax incentives all have a major impact on decisions made by manufactures regarding where to design, produce, assemble and market their products.

The need to satisfy varying customers' demands gave rise to increased flexibility not only in manufacturing systems but also in the product structure through modularity and platform concepts. Mass customization and postponing or moving products differentiation as close as possible to point-of-sale, if applied carefully, can be very beneficial. The protection of intellectual properties and trade-secrets play a role in deciding how a product is broken down into modules, what is contained in each module and where it would be produced.

Variations in the currency exchange rates require careful attention particularly in globally distributed supply chains. Since one of the major criteria for making strategic decisions in supply chain is the overall allocation costs (production, inventory, transportation), they should be calculated considering the in-site currency exchange rate forecasts.

As shown in Figure 1 although the currency exchange variations may be negligible in the short term they become more significant in long term and strategic decisions1[1].

Therefore, it is important to consider those currency trends and exchange rates where suppliers, Manufacturers and markets are located.

Responsiveness and agility are becoming important competitive attributes in addition to quality, variety and price. This leads to employing the concept of 3-dimensional concurrent engineering (3D-CE), as a step beyond design for supply chain and concurrent engineering. This concept was first discussed by Fine (1998) to understand and coordinate the interdependencies among product and process design and supply chain decisions, to maximize the operational and supply chain performance. Since it is the product design that determines which materials, components, and finished products should flow through the

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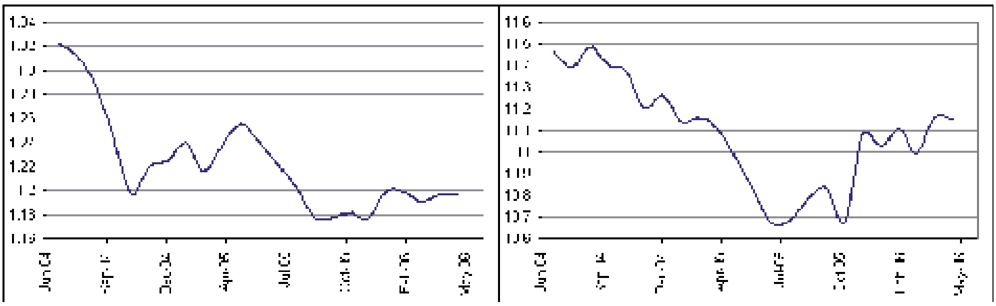
[1] These information are provided from http://www.forecasts.org/exchange-rate/

supply chain, considering the available supply chain locations, their capacity, costs and their demands while designing a product would help determine the optimum product design and modular structure. Furthermore, by considering different product design alternatives while configuring the supply chain, the optimum locations and capacities of various nodes can be defined.



Canadian Dollar to US Dollar   Mexican Peso to US Dollar

Figure 1. Currency Excange Rate (Past Trend , Present Value and Future Projection)

In this paper, a comprehensive decision support model has been developed to concurrently determine the optimal product modularization scenario and the global supply chain configuration in a 3 echelon (suppliers, manufacturing facilities and distribution centers) global supply chain system considering the procurement costs, production, inventory and transportation costs along with the impact of changes in the global market currency exchange rates. The proposed model combines the product design modular configuration problem (including modules make/buy options and the product modular structure alternatives) and the supply chain design configurationproblem (including different locations for suppliers, manufacturers and distribution centers). The application of the decision support model is evaluated using historical data from an automobile wipers system manufacturer.

In section 2 the relevant literature is reviewed. Section 3 describes the developed global supply chain decision making mathematical model and section 4 analyzes the proposed decision making model using data for a generic globally distributed supply chain for an industrial product. Finally in section 5 the conclusions and the future research direction for this line of research are presented.

2. Literature review

In the 1990's the emphasis on synchronizing supply chain management decisions with product design decisions resulted in another aspect of design for X (DFX) series called design for supply chain management (DFSC) defined as "designing products and processes so that the supply chain related costs and performance can be more effectively managed". Economic packaging, concurrent and parallel processing and postponement strategies (Time and Form) are the three key components of design for supply chain management and commonality, standardization and modularity are some of the important concepts to implement postponement.

In 1995, Nielsen and Holmstrom studied the benefits of taking account of supply chain considerations in the design and process engineering stages in a European car manufacturer offering a large number of options with each model. They argued that designing common components and creating variety at the final assembly stage (postponement) can be a good alternative to pilling inventory of each product variation (high inventory cost) or waiting for the suppliers to deliver the customized product (delay cost). Lee & Sasser (1995) studied the impact of employing principles of design for supply chain for new product development atHewlett Packard (HP) Company, using a standard design for power supply units for HP printers that is applicable in both North America and Europe markets instead of using dedicated power supplies for each market. They developed an analytical model to quantify the complex impacts and benefits of cost drivers like, stock-outs, reconfigurations, manufacturing, logistics and inventory. In another study at HP, Feitzinger & Lee (1997) discussed employing postponement strategy for the assembly of the power supply using a modular design. Garg (1999) studied three product and process modular design alternatives, which differ in their number of supply chain stages and the sequence of some of the processes, for a new line of products to identify the feasible set of product and process designs in terms of their total inventory cost using the Supply Chain Modeling and Analysis Tool (SCMAT).

Many researchers have recently focused on the application and implementation of 3D-CE to maximize operational, supply chain and firm performance. Fixon (2005) argued that the product architecture, when properly defined and articulated, can serve as a coordination mechanism and presented a multi-dimensional framework for a comprehensive assessment of product architecture. Huang et al., (2005) applied an optimization model to study the impact of platform products, with and without commonality, on decisions related to supply chain configuration. They define the scope of supply chain configuration decisions quite broadly to include supplier selection, selection of transportation delivery modes, determination of inventory quantities and stocking points, manufacturing processes to use and production time. Su et al., (2005), applied queuing theory to evaluate time and form postponement structures in a supply chain. Blackhurst at al., (2005), deployed a network-based approach to develop and formalize the Product Chain Decision Model (PCDM), for describing the operation of a supply chain while considering decisions related to product design and manufacturingprocess design and the impact of such decisions on the supply chain. Petersen et al., (2005), discussed the integration of suppliers into the new product development process and their direct implications on manufacturing process design decisions and supply chain configuration decisions. Fine et al., (2005), proposed a quantitative 3-dimensional concurrent engineering (3-DCE) formulation using a weighted goal programming approach to facilitate the assessment of trade-offs among potentially conflicting objectives.

Extensive research can be cited discussing supply chain structures and performance. In 1998, Van Hoek, introduced a framework to analyze the configuration of supply chain in the context of global strategy and showed that implementation of postponed manufacturing not only requires the reconfiguration of the logistic systems but also other operations in the supply chain. Karabakal et al., (2000), studied the American Volkswagen's vehicle distribution system and presented a combination of simulation and discrete optimization models to analyze the alterative designs in terms of costs and customer service level. Hahn et al., (2000), addressed the supply chain synchronization problem in Hyundai Motor

Company and discussed the mechanism used in order to coordinate production planning and scheduling activities among supply chain members.

Thonemann & Bradely (2002), presented a mathematical model to analyze the effect of product variety on supply-chain performance, measured in terms of expected lead time and cost at the retailers, for a single manufacturer and multiple retailers supply chain. Salvador, Rungtusanatham & Forza (2004) performed an empirical study on European firms in telecommunications, transportation vehicles and food processing equipment industries and explored how the firms supply chain should be configured when different degrees of customization are offered. Tyagi et al., (2004), developed a decision-support systemShi, and to optimize the two echelon global manufacturing supply chain for high performance polymer division in GE plastics company to maximize contribution margin while taking into consideration product demands and prices, plant capacities, production costs, distribution costs and raw material costs. Billington et al. (2004) highlighted the application of HP's new inventory optimization technique to prove supply chain networks design within HP's digital camera and inkjet supplies. In 2005, Nagel et al. proposed a multi objective evaluation method for reconfiguring supply chains based on discrete event simulation. They considered cost-based, environmental and performance-based objectives as their evaluation criteria in their study. Nembhard & Aktan, (2005) developed a supply chain model in which a manufacturing firm can have the flexibility to select different suppliers, plant locations, and market regions and there can be an implementation time lag for the supply chain operations. A real options approach was used to estimate the value of flexibility and determine the optimum strategy to manage it under uncertain currency exchange rates.

Forecasting currency exchange rates has always been considered by many researchers to reduce the uncertainties and risk of decision making in different areas. Weigend et al., (1991), Prasolov & WeI, (2000), Nasution & Agah, (2000), Chandhok & Terry, (1986), Rast, (2000) and Paramunetilleke & Wong, (2002), are some of the studies on the development of different methods to forecast the currency exchange rates and their performance.

Little work has been done on the development of decision support models for concurrent supply chain and product module structure design considering the global issues in supply chain design. Our proposed decision support model is unique in the sense that it supports concurrent design of product module structure and supply chain configuration while considering the currency exchange rate variations in a global supply chain environment.

3. Global supply chain model

An optimization-based decision support model, which determines the best way to split production and procurement of a product modules for a global supply chain system is proposed. It selects the optimal set of product module structure and the corresponding supply chain configuration taking into consideration the currency exchange rate in each period at each location while minimizing the overall system cost. Figure 2 shows the generic supply chain and the points of currency exchange rate considerations.

The decision support model is formulated using mathematical programming where the decision variables are, NM_{pnmsit} , as the number of module i purchased in period t from supplier s to produce product n under scenario m at plant p. X_{pnmt} as the number of units of Scenario m of product family n produced at Plant p in period t. I_{pnt} , as the inventory of product family n in Plant p at the end of period t. $TU_{pkt,}$ the number of transportation units used to ship products from Plant p to distribution center k in period t. O_{pt}, total overtime scheduled at Plant p *in period t*. W_{pt}, total regular labor-hours available for Plant p in period. Y_{pnkt} as the Units of product family n shipped from Plant p distribution center k in period t. ITpnkt , in-transit inventory of product family n from Plant p, to distribution center k at the end of period t and Inkt , inventory of product family n at distribution center k at the end of period t.

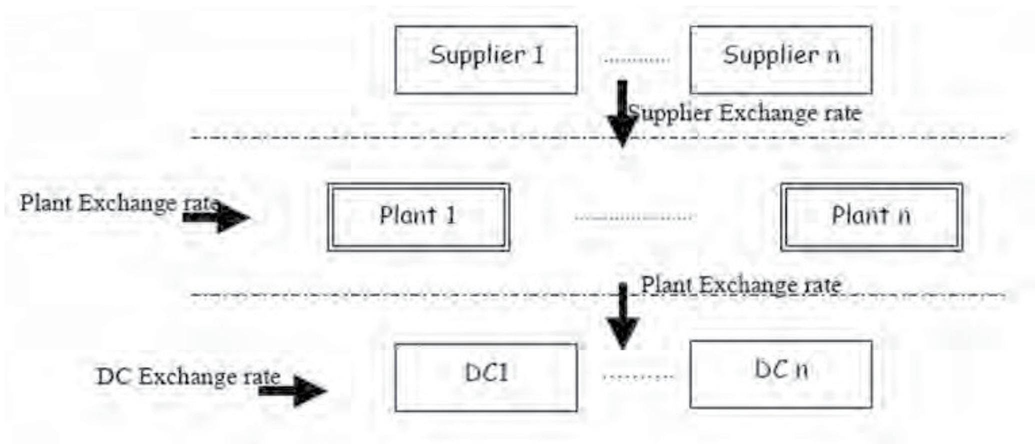


Figure 2. Generic supply chain with exchange rate considerations points

The objective is to minimize the overall following supply chain cost over the planning horizon:
Procurement cost:

$$\sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{m=1}^{M} CM_{pnmsi} NM_{pnmsi} EX_{st} \tag{1}$$

Where:
CM_{pnmsi} : Cost of purchasing module i from supplier s to produce product n at plant p (includes transportation cost)
EX_{st} : Currency exchange rate at supplier s in period t
Production cost:

$$\sum_{p=1}^{P}\sum_{t=1}^{T} L_p EX_{pt} W_{pt} \tag{2}$$

Where:
L_p: Fixed cost per regular labor hour at plant p
EX_{pt} : Currency exchange rate at plant p in period t
Total overtime cost:

$$\sum_{p=1}^{P}\sum_{t=1}^{T} L_p^{`} EX_{pt} O_{pt} \tag{3}$$

Where:
$L^{`}_p$: Cost of one labor hour on overtime at plant p

Total transportation cost (from plant to DC):

$$\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{t=1}^{T} TC_{pk} EX_{pt} TU_{pkt} \tag{4}$$

Where:
TC_{pk} : Fixed cost of transporting one consignment from plant *p* to distribution center *k*
Cost of carrying inventory at plants:

$$\sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{t=1}^{T} h_{pn} EX_{pt} I_{pnt} \tag{5}$$

Where:
h_{pn} : Inventory carrying cost of product family *n* at plant *p* held for one period
Cost of carrying in-transit inventory:

$$\sum_{p=1}^{P}\sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{t=1}^{T} Th_{pn} EX_{pt} IT_{pnkt} \tag{6}$$

Where:
Th_{pn} : In-transit inventory cost for a unit of product family *n*, produced at plant *p* held for one period
Cost of carrying inventory at distribution centers:

$$\sum_{n}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T} h_{nk} EX_{kt} I_{nkt} \tag{7}$$

Where:
h_{nk} : The corresponding inventory carrying cost
EX_{kt} : Currency exchange rate at distribution center *k* in period *t*
Subject to the following labor, capacity and transportation constraints:
Resource adjustment:

$$\sum_{n=1}^{N}\sum_{m=1}^{M} a_{pmn} X_{pmnt} = W_{pt} + O_{pt} \quad (\forall\ p\ \ 1 \ldots P,\ t\ \ 1 \ldots T) \tag{8}$$

Total required labor hour in anytime period is assumed to be equal to the available regular labor hours plus the overtime labor hours.
Shipment balance at plant p:

$$\sum_{k=1}^{K} Y_{pnkt} \le I_{pn(t-1)} + \sum_{m=1}^{M} X_{pmnt} \quad (\forall p=1 \ldots P,\ n=1 \ldots N,\ t=1 \ldots T) \tag{9}$$

The amount of product family *n* produced at Plant *p* that is shipped to the distribution center *k* in period *t* cannot exceed last period's inventory level plus that period's production.
Plant warehouse capacity:

$$\sum_{n=1}^{N} S_n I_{pnt} \le IC_p \quad (\forall p=1 \ldots P,\ t=1 \ldots T) \tag{10}$$

Space required by the net inventory at Plant p in any time period should not exceed the availablestorage space.
Distribution center warehouse capacity:

$$\sum_{n=1}^{N} S_n I_{nkt} \le IC_k^t \quad (\forall\ k=1\ldots K,\ t=1\ldots T) \tag{11}$$

The space required by the net inventory at each distribution center in any time period t shouldnot exceed the available storage space.
Inventory balance at plant p:

$$I_{pnt} = I_{pn(t-1)} + \sum_{m=1}^{M} X_{pmnt} - \sum_{k=1}^{K} Y_{pnkt} \ ,\ (\forall p\ \ 1\ldots P,\ n\ \ 1\ldots N,\ t\ \ 1\ldots T) \tag{12}$$

In any period, the inventory of product family n at Plant p is equal to the last period's inventory plus the production level of the product, minus the total shipments of product family n to all distribution centers in the same period.
In-transit inventory balance:

$$IT_{pnkt} = IT_{pnk(t-1)} + Y_{pnkt} - Y_{pnk(t-LT_{pk})} \quad ,(\forall p\ \ 1\ldots P,\ n\ \ 1\ldots N,\ k\ \ 1\ldots K,\ t\ \ 1\ldots T) \tag{13}$$

In any time period, the in-transit inventory of product family n produced at manufacturing facility p being shipped to distribution center k is equal to the last period's in-transit inventory plus the shipments sent from manufacturing facility p in that period minus the received shipments at distribution center k in the same period.
Inventory balance at distribution center k:

$$I_{nkt} = \sum_{p=1}^{P} Y_{pnk(t-LT_{pk})} + I_{nk(t-1)} - D_{nkt} \qquad (\forall,\ n=1\ldots N,\ k=1\ldots K,\ t=1\ldots T) \tag{14}$$

In any time period, the inventory of product family n at distribution center k is equal to the last period's inventory plus total received shipments in that period minus the demand in the same period.
Number of transportation consignments:

$$\frac{\sum_{n=1}^{N} V_n Y_{pnkt}}{FTL} \le TU_{pkt} \ \ (\forall\ p=1\ldots P,\ k=1\ldots K,\ t=1\ldots T) \tag{15}$$

In any time period, the number of consignments shipped from Plant p to distribution center k should be greater than or equal to the total volume required by the products shipped, divided by the volume capacity of the transportation consignment.
In addition, a decentralized safety stock policy is employed since the new market trends make customer satisfaction the main objective of each service activity. Hence, those inventory policies that keep inventories closer to the customers are most preferred in order to increase the customer satisfaction and service level.
Decentralized safety stock (at distribution centers):

$$I_{nkt} \ge \lambda D_{nk(t+1)} + \left(z_a \sigma_{nk} \sqrt{MLT_{pn} + TLT_{pk}}\right) \ \ (\forall p=1\ldots P,\ n=1\ldots N,\ k=1\ldots K,\ t=1\ldots T) \tag{16}$$

In any time period, the inventory at a distribution center k should be at least equal to a pre-specified percentage (λ) of the next period's demand plus the safety stock. Also the balance between the production level and the number of components purchased are controlled by:

$$X_{pmnt} = \sum_{s=1}^{S} (NM_{pmnsit}) / BOM_{pmni} \qquad (\forall p=1\ldots P,\ n=1\ldots N,\ m=1\ldots M,\ t=1\ldots T,\ i=1\ldots I) \tag{17}$$

At any period t the production level of product family n at plant p is equal to the total number of module i purchased from all the suppliers divided by number of module i required to produce one unit of product n at plant p.
It should be noted that the cost of lost sales and backorders are not considered in the above model. Also it is assumed that the manufacturing lead-time for different scenarios does not change. The increase in the required labor hour for different scenarios justifies this assumption.

4. Case study

An example of an automobile wiper system is used for illustrating the application of the proposed decision support model. The planning horizon is 4 periods and the supply chain consists of 7 suppliers, 5 plants and 6 distribution centers that are globally distributed as shown in Table 1.

Plants location	Distribution centre locations
North America 1	North America 1
North America 2	North America 2
North America 3	Asia 1
Asia	Europe
Europe	Asia 2
-	Asia 3

Table 1. Locations of Plants and Distribution centers

Automobile Wipers, whether located on the windshield, rear window, or headlights, are used to clear rain, sleet, snow, and dirt. A typical wiper system consists of four main modules; rubber blades, metal arms, electric motor (to move the arms and blades) and the linkages to move the blades as shown in Figure 3.

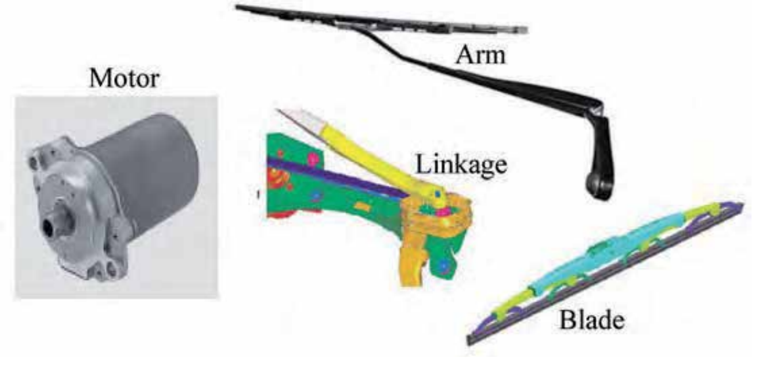


Figure 3. Wiper system Components

4.1 Product modular structure

It is assumed that the motor may be purchased either as an assembled motor module or its components may be purchased separately and the final assembly and

fabrication of the motor is performed at the manufacturing facility. The motor consists of the following major components:
Board, Case and plugs. Table 2 shows the components and their available supplier locations.

Supplier`s location	Supplied components
North America 1	Motor, Board
Asia 1	Motor, Board
Europe 1	Motor, Board
North America 2	Arms, Blades, Case, Plugs
Asia 2	Arms, Blades, Case, Plugs, Linkages
Europe 2	Arms, Blades, Linkages
North America 2	Case, Plugs, Linkages

Table 2. Components and their Suppliers

There are two different scenarios of product modules structure to be considered according to the above motor acquisition alternatives as shown in Figure 4.

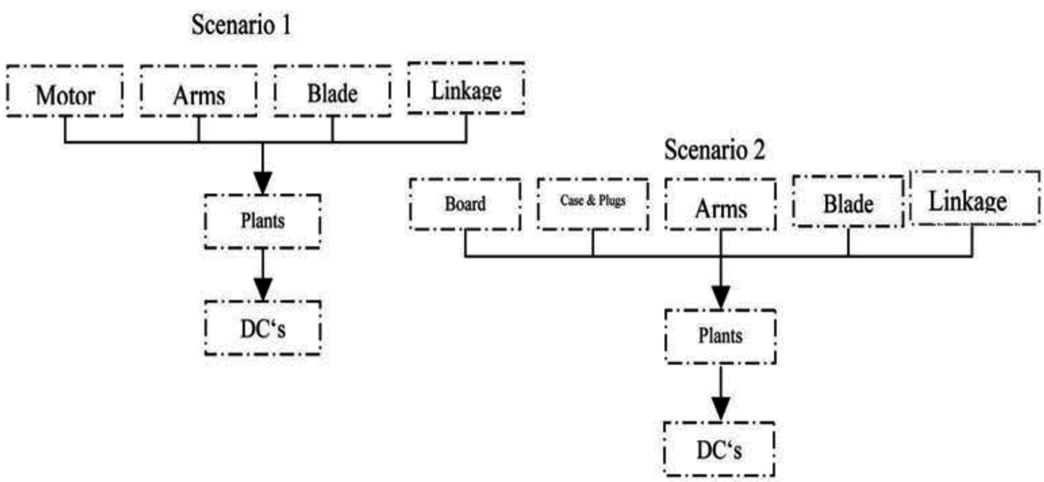


Figure 4. Available product design scenarios

The Lingo (Lindo Systems Inc., 2005) optimization tool is used as the solver for the above ILP decision support model to find the optimal set of supply chain configuration and product module structure scenario for this specific example,. The optimal solution selected the product modular structure scenario #2 and the supply chain network configuration shown in Figure 5 with a total cost of $ 34,607,460.
In this example, purchasing the motor components from the proper supplier and performing the assembly at the manufacturing facility is more cost effective than buying the assembled motor module. Although the market is stronger (higher demand) in North America, because of the lower costs in Europe and Asia, the model tends to choose locations in those areas for suppliers and manufacturing facilities.

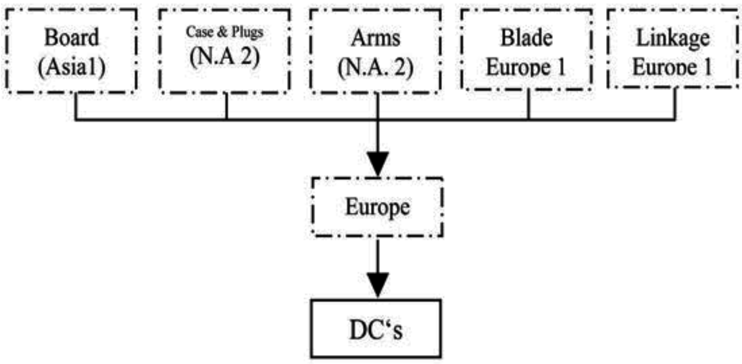


Figure 5. optimal set of product structure scenario and supply chain configuration

4.2 Model applications

4.2.1 Currency considerations

One of the unique applications of this model is analyzing the impact of variations in the currency exchange rate on the configuration of the supply chain. This is useful specially while designing the initial configuration of the supply chain network since this model not only gives the optimum supply chain configuration but it can also be used to analyze the impact of currency variation at each node of the network on the optimum supply chain configurations. For this purpose it is assumed that as a result of economical and industrial evolution the currency value for supplier North America 2 becomes 6% stronger. Figure 6 shows the optimal supply chain configuration under this scenario. As shown in Figure 6 this change in the exchange rate, results in a new optimal solution in which supplier North America 2 is no longer optimal for "Case & Plugs" and "Arms", instead the model suggests that in this case it is optimal to outsource supplying these components from Asia 2.

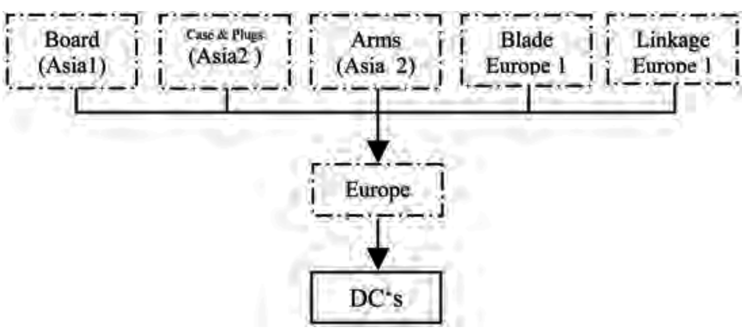


Figure 6. Optimal set of product structure scenario and supply chain configuration under changes in the currency exchange rate

Also the presented model can be applied to determine the optimal initial configuration of global supply chains. In another words, since the currency exchange rates are considered in the decision making process in this model using the present, optimistic and pessimistic currency exchange rate forecasts, one could decide about the best supply chain design in view of the possible trends in the exchange rates and determine the critical locations through the supply chain. Table 3 shows the extent of variations in the currency exchange rate under which the present solution would remain optimum.

Supplier`s location	Variation range
Board	5
Case/Plugs	6
Arms	6
Blades	2.5
Linkage	3
Plant location	3.5

Table 3. Currency Exchange Rate Variation Range for the Present Optimal Solution.

4.2.2 Demand shifts

Another application of the developed model is concerned with one of the recent issues in the global supply chain decision making. The question is how the increase in Asian market demand and the recent shift in market trends- from North America ranking first to Asian markets beingthe highest ranked market- will affect the decision making in global supply chains?

New demand data (with Asia ranking first, North America second and Europe third) was used for the example under consideration to explore its effect. The change in the market demand affected did not affect the optimal product structure design but did change the optimal supply chain network configuration as shown in Figure 7. It should be noted that this result is data dependent and can not be generalized. However, the developed model can be used to evaluate any scenario given its specific set of data and constraints.

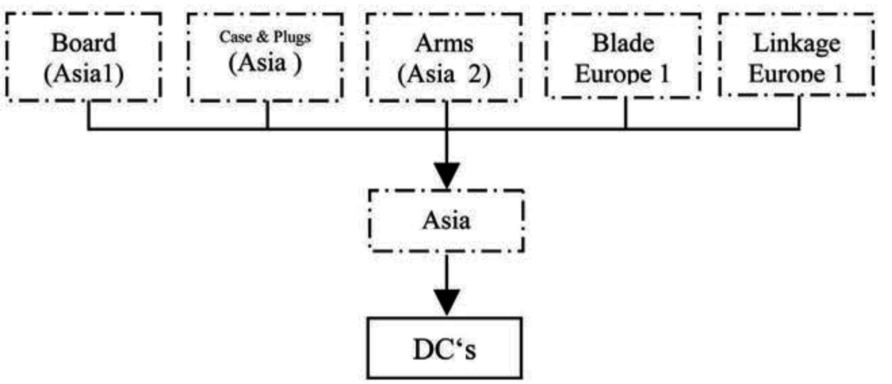


Figure 7. optimal set of product structure scenario and supply chain configuration under changes in the market demand

4.2.3 Postponement strategies in product design and supply chain configurations

Postponement is one of the strategies for managing supply chain integration along with mass customization and modularization. While the goal of mass customization is to produce customized goods at low costs, postponement focuses on delaying such customization and implementing it as close to the customers as possible. The extent of customization and postponement of products is rooted in modularization of product structure designs (Mikkola & Larsen, 2004).In the broadest terms, postponement is a strategy whereby some of the activities in the supply chain are not performed until customer orders are received. According to Lee (1998) postponement is about delaying the timing of crucial processes in which end products assume their specific functionalities, features and identities. It was originally proposed as an approach to reduce the risk and uncertainty costs tied to the differentiation of goods. The logic behind postponement is that, the delay leads to the availability of more information, thus improving the quality of decision making, and also avoids building up inventories of finished goods in anticipation of future orders.

Postponement is categorized as Form and Time postponement. Form postponement is closely related to modularization and calls for a fundamental change of the product architecture by using designs that standardize some of the components (hence changing the form of the product architecture) or process steps. It involves delaying the differentiation of the products until later stages of the supply chain. Time Postponement involves delaying the differentiation of the products until later stages of the supply chain. The proposed model was used to analyze the impact of employing postponement strategy on the configuration and performance of supply chain. A new product modular design structure scenario, that implements form postponement by delaying the differentiation of the products until later production stages, was introduced. For this analysis an additional term that represents the differentiation cost, due to the work done at distribution centers, was added to the model.

Cost of differentiation at

$$DC: \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T} D_{nkt} EX_{kt} DF_{nkt} \tag{18}$$

DF_{nkt} : Cost of differentiation for one unit of product *n* at distribution center *k* at period *t*

This differentiation cost stands for the final assembly and fabrication of the products that has been postponed from manufacturing plant to distribution centers to increase the responsiveness and customization level of the system. Some data adjustments were required for demand, production cost at and demand forecast errors to show employment of postponement strategy.

Figure 6. Safety stock level with /without postponement strategy

In this example, purchasing the motor components from the proper supplier and performing the assembly at the manufacturing facility is more cost effective than buying the assembled motor module. Although the market is stronger (higher demand) in North America, because of the lower costs in Europe and Asia, the model tends to choose locations in those areas for suppliers and manufacturing facilities.
In this example, the choice of employing postponement strategy did not affect the optimal supply chain configuration but it affected the total cost of the supply chain as explained above.

4.2.4 Other applications of the model

Another application of this decision support model would be analyzing the impact of introducing a new product modular structure on the optimal configuration of the supply chain network. The output data of the model can also be used to determine the effect of variation in the exchange rates, or suppliers' costs on the optimum supply chain configuration and product modular design scenarios. This information would help the managers in making better decisions considering all the possible options.

5. Discussion and conclusions

Present competitive global market with ever increasing demand for high quality customized product, calls for a more agile response from the organization and its partners in the supply chain along with an optimized and globally integrated configuration for the supply network. The idea in the past was that marketing success was based upon strong brands and innovative technologies. Instead today the winning combination is strong brands and innovative technologies supported by an integrated supply chain capable of responding more quickly to volatile market demand and changing conditions. Manufacturing enterprises need to focus their effort on achieving greater agility and responsiveness planning, predicting and reacting quickly to the market changes by selecting the proper supply chain configuration and appropriate product modular design structure while considering the globalization factors such as monetary valuations trends.
The proposed decision support model captures some of the critical aspects of supply chain and product design architecture to concurrently determine the optimal modular product structure and the global supply chain configuration in a 3 echelon (suppliers, manufacturing facilities and distribution centers) global supply chain system considering the procurement costs, production, inventory and transportation costs along with the impact of changes in the global market currency exchange rates. The proposed model is a combination of the product design configuration problem (including the modular options and the product design strategy alternatives) and the supply chain design configuration problem (including different locations for suppliers, manufacturers and distribution centers). The use of the developed decision support model has been illustrated using an example of automobile wipers system.
In this model, estimates of currency exchange rates were used as input parameters. There are methods to calculate and forecast the currency exchange rates (Yang & Burns, 2005). Using these methods to calculate and make short and long term forecastscan provide more dynamic estimates.
Product demand and production and transportation lead-time are also assumed to be fixed numbers in this model but considering the stochastic nature of these factors,

including their probability distributions would improve the quality of the decision made using the proposed model. Introducing different product design strategies like platform design or strategies influenced by Intellectual Property considerations, considering other supply chain node locations, or including additional supply chain performance indexes like, suppliers' quality and lead-time, responsiveness, customer service level and environmental factors in the objective function of the decision support model would be worthwhile exploring.

Countries and governments compete in attracting international investments and jobs by offering attractive packages of leverage contribution schemes, international trade agreements and tax incentives. Any decisions regarding locating manufacturing facilities for products and their modules and selecting suppliers must factor in all these considerations, in the context of location- specific monetary values along with the site-specific exchange rates, while trying to minimize total cost of the global supply chain and maximize profit.

6. Acknowledgement

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17

Quantitative Models for Centralised Supply Chain Coordination

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1. Introduction

A supply chain is defined as a network of facilities and distribution options that perform the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Managing such functions along the whole chain; that is, from the supplier's supplier to the customer's customer; requires a great deal of coordination among the players in the chain. The effectiveness of coordination in supply chains could be measured in two ways: reduction in total supply chain costs and enhanced coordination services provided to the end customer — and to all players in the supply chain.

Inventory is the highest cost in a supply chain accounting for almost 50% of the total logistics costs. Integrating order quantities models among players in a supply chain is a method of achieving coordination. For coordination to be successful, incentive schemes must be adopted. The literature on supply chain coordination have proposed several incentive schemes for coordination; such as quantity discounts, permissible delay in payments, price discounts, volume discount, common replenishment periods.

The available quantitative models in supply chain coordination consider up to four levels (i.e., tier-1 supplier, tier-2 supplier, manufacturer, and buyer), with the majority of studies investigating a two-level supply chain with varying assumptions (e.g., multiple buyers, stochastic demand, imperfect quality, etc). Coordination decisions in supply chains are either centralized or decentralized decision-making processes. A centralized decision making process assumes a unique decision-maker (a team) managing the whole supply chain with an objective to minimize (maximize) the total supply chain cost (profit), whereas a decentralized decision-making process involves multiple decision-makers who have conflicting objectives.

This chapter will review the literature for quantitative models for centralised supply chain coordination that emphasize inventory management for the period from 1990 to end of 2007. In this chapter, we will classify the models on the basis of incentive schemes, supply chain levels, and assumptions. This chapter will also provide a map indicative of the limitations of the available studies and steer readers to future directions along this line of research.

2. Centralised supply chain coordination

A typical supply chain consists of multistage business entities where raw materials and components are pushed forward from the supplier's supplier to the customer's customer. During this forward push, value is gradually added at each entity in the supply chain transforming raw materials and components to take their final form as finished products at the customer's end, the buyer. These business entities may be owned by the same organization or by several organizations.

Goyal & Gupta (1989) suggested that coordination could be achieved by integrating lot-sizing models. However, coordinating orders among players in a supply chain might not be possible without trade credit options, where the most common mechanisms are quantity discounts and delay in payments.

There are available reviews in the literature on coordination in supply chains. Thomas & Griffin (1996) review the literature addressing coordinated planning between two or more stages of the supply chain, placing particular emphasis on models that would lend themselves to a total supply chain model. They defined three categories of operational coordination, which are vendor–buyer coordination, production-distribution coordination and inventory-distribution coordination. Thomas & Griffin (1996) reviewed models targeting selection of batch size, choice of transportation mode and choice of production quantity. Maloni & Benton (1997) provided a review of supply chain research from both the qualitative conceptual and analytical operations research perspectives. Recently, Sarmah et al. (2006) reviewed the literature dealing with vendor–buyer coordination models that have used quantity discount as coordination mechanism under deterministic environment and classified the various models. Most recently, Li & Wang (2007) provided a review of coordination mechanisms of supply chain systems in a framework that is based on supply chain decision structure and nature of demand. These studies lacked a survey of mathematical models so the reader may detect the similarities and differences between different models. This chapter does so and updates the literature.

The body of the literature on coordinating order quantities between entities (level) in a supply chain focused on a two-level supply chain for different assumptions. A two-level supply chain could consist of a single vendor and a single buyer, or of a single vendor and multiple buyers. Few works have investigated coordination of orders in a three-level (supplier→vendor→buyer) supply chain, and described by paucity those works that assumed four levels (tier-2 suppliers → tier-1 suppliers → vendor → buyer) or more.This chapter will classify the models by the number of levels, and therefore, there are three main sections. Section 3 reviews two-level supply chain models. Three-level models are discussed in section 4. Models with four or more levels are discussed in section 5.

3. Two-level supply chain models

The economic order quantity (EOQ) model has been the corner stone for almost all the available models in the literature. In a two-level chain, with coordination, the vendor (e.g., manufacturer, supplier) and the buyer optimize their joint costs.

The basics

Consider a vendor (manufacturer) and a buyer who each wishes to minimize its total cost. A basic model assumes the following: (1) instantaneous replenishment, (2) uniform and

constant demand, (3) single non-perishable product of perfect quality, (5) zero lead time, and (6) infinite planning horizon.
The buyer's unit time cost function is given as

$$TC_b(Q) = \frac{A_b D}{Q} + h_b \frac{Q}{2} \tag{1}$$

The optimal order quantity that minimizes (1) is $Q^* = \sqrt{2A_b D/h_b}$, where A_b is the buyer's order cost , h_b is the buyer's holding cost per unit per unit time, and D is the demand rate per unit time and assumed to be constant and uniform over time. Substituting Q^* in (1), then (1) reduces to $TC_b^* = \sqrt{2A_b D h_b}$. The vendor's unit time cost function is given as

$$TC_v(\lambda) = \frac{A_v D}{\lambda Q} + h_v \frac{Q}{2}(\lambda - 1) \tag{2}$$

Where A_v is the vendor's order (setup) cost, h_v is the vendor's holding cost per unit per unit time, and λ being the vendor lot-size multiplier (positive integer) of the buyer's order quantity Q.

<u>From the buyer's perspective</u>

If the buyer is the supply chain leader, then it orders Q^* every $T^* = Q^*/D$ units of time. Accordingly, the vendor treats Q^* as an input parameter and finds the optimal λ that minimizes its unit time cost, where $TC_v(\lambda^* - 1) > TC_v(\lambda^*) < TC_v(\lambda^* + 1)$. For this case, the vendor is the disadvantaged player. An approximate closed form expression is possible by assuming (2) to be differentiable over λ, then the optimal value of λ is given as

$$\lambda^* = \frac{1}{Q^*}\sqrt{\frac{2A_v D}{h_v}} = \sqrt{\frac{2A_v D}{h_v} \times \frac{h_b}{2A_b D}} = \sqrt{\frac{A_v h_b}{A_b h_v}} \tag{3}$$

For example, if the λ = 2.58, then λ^* =2 if $TC_v(\lambda^* = 2) < TC_v(\lambda^* + 1 = 3)$; otherwise, λ^* =3. The vendor may find the lot-for-lot (λ^* = 1) policy to be optimal if

$$\frac{A_v D}{Q} < \frac{A_v D}{\lambda Q} + h_v \frac{Q}{2}(\lambda - 1) \Rightarrow \frac{A_v D}{Q}\left(\frac{\lambda - 1}{\lambda}\right) < h_v \frac{Q}{2}(\lambda - 1) \Rightarrow \frac{A_v D}{Q\lambda} < h_v \frac{Q}{2} \Rightarrow \lambda > \frac{2A_v D}{h_v Q^2}.$$

<u>From the vendor's perspective</u>

The buyer's EOQ may not be optimal to the vendor. From a vendor's perspective, the optimal order quantity is given from differentiating (2) over Q and solving for Q to get

$$Q^{**} = \sqrt{\frac{2A_v D}{h_v \lambda(\lambda - 1)}}, \text{ where } \lambda > 1 \tag{4}$$

Then the optimal value of (2) as a function of $\lambda > 1$ is given as

$$TC_v^*(\lambda) = \sqrt{\frac{2A_v D h_v(\lambda - 1)}{\lambda}} \tag{5}$$

The optimal cost occurs when $TC_v^*(\lambda^{**}-1) > TC_v^*(\lambda^{**}) < TC_v^*(\lambda^{**}+1)$. For this case, the buyer is the disadvantaged player. The ideal case would occur when the EOQ of the buyer matches that of the vendor, i.e., $Q^* = Q^{**}$, where

$$\frac{A_v}{h_v\lambda(\lambda-1)} = \frac{A_b}{h_b} \Rightarrow \frac{A_v h_b}{A_b h_v} = \lambda(\lambda-1) \Rightarrow \lambda^2 - \lambda - \frac{A_v h_b}{A_b h_v} = 0 \Rightarrow \lambda^* = \frac{1+\sqrt{1+4A_v h_b/A_b h_v}}{2} \geq 2$$

$$\Rightarrow \sqrt{1+4A_v h_b/A_b h_v} \geq 3 \Rightarrow A_v h_b/A_b h_v \geq 2$$

Vendor-buyer coordination

In many cases, there is a mismatch between the quantity ordered by the buyer and the one that the vendor desires to sell to the buyer. A joint replenishment policy would be obtained by minimizing the joint supply chain cost which is given as

$$TC_{sc}(Q,\lambda) = TC_b(Q) + TC_v(\lambda) = \frac{A_b D}{Q} + h_b\frac{Q}{2} + \frac{A_v D}{\lambda Q} + h_v\frac{Q}{2}(\lambda-1) \tag{6}$$

Goyal (1977) is believed to be the first to develop a joint vendor-buyer cost function as the one described in (6). Differentiating (6) over Q and solving for Q to get

$$Q(\lambda) = \sqrt{\frac{2D(\lambda A_b + A_v)}{h_b\lambda + h_v\lambda(\lambda-1)}} \tag{7}$$

The order quantity in (7) is larger than the buyers EOQ for every $\lambda \geq 1$, which means higher cost to the buyer. This can be shown by setting $Q(\lambda) > Q^*$ to get $(\lambda A_b + A_v)/[h_b\lambda + h_v\lambda(\lambda-1)] > A_b/h_b$. Some researchers added a third cost component to the cost function in (6). For example, Woo et al. (2000) studied the tradeoff between the expenditure needed to reduce the order processing time and the operating costs identified in Hill (1997), by examining the effects of investment in EDI on integrated vendor and buyer inventory systems. Another example is the work of Yang & Wee (2003) who incorporated a negotiation factor to balance the cost saving between the vendor and the buyer.

To make coordination possible, the vendor must compensate the buyer for its loss. This compensation may take the form of unit discounts and is computed as

$$d = \frac{TC_b(Q(\lambda)) - TC(Q^*)}{D}$$

$$= A_b\sqrt{\frac{h_b\lambda + h_v\lambda(\lambda-1)}{2D(\lambda A_b + A_v)}} + h_b\sqrt{\frac{(\lambda A_b + A_v)}{2D[h_b\lambda + h_v\lambda(\lambda-1)]}} - \sqrt{\frac{2h_b A_b}{D}} \tag{8}$$

Crowther (1964) is believed to be the first who focused on quantity discounts from the buyer-seller perspective. For a good understanding of the precise role of quantity discounts and their design, readers may refer to the works of Dolan (1987) and Munson & Rosenblatt (1998).

Recently, Zhou & Wang (2007) developed a general production-inventory model for a single-vendor–single-buyer integrated system. Their model neither requires the buyer's unit holding cost be greater than the vendor's nor assumes the structure of shipment policy. Zhou & Wang (2007) extended their general model to consider shortages occurring only at the buyer's end. Following, their production-inventory model was extended to account for deteriorating items. Zhou & Wang (2007) identified three significant insights. First, no matter whether the buyer's unit holding cost is greater than the vendor's or not, they claimed that their always performs best in reducing the average total cost as compared to the existing models. Second, when the buyer's unit holding cost is less than that of the vendor's, the optimal shipment policy for the integrated system will only comprise of shipments increasing by a fixed factor for each successive shipment. Very recently, Sarmah et al. (2007) considered a coordination problem which involves a vendor (manufacturer) and a buyer where the target profits of both parties are known to each other. Considering a credit policy as a coordination mechanism between the two parties, the problem's objective was to divide the surplus equitably between the two parties.

In the following sections, we survey the studies that extended upon the basic vendor-buyer coordination problem (two-level supply chain) by relaxing some of its assumptions. The following sections are: (1) finite production rate, (2) non-uniform demand,(3) permissible delay in payments, (4) multiple buyers, (5) multiple Items, (6) product/process quality, (7) deterioration, (8) entropy cost and (9) stochastic models.

Finite production rate

Banerjee (1986) assumed finite production rate rather than instantaneous replenishment. He also assumed a lot-for-lot (λ = 1) policy. Banerjee's cost function which is a modified form of (6) is given as

$$TC_{sc}(Q) = \frac{A_b D}{Q} + h_b \frac{Q}{2} + \frac{A_v D}{Q} + h_v \frac{D}{P} Q \tag{9}$$

Where $h_b = Ic_b$ and $h_v = Ic_v$ in which c_v is the vendor's unit purchase (production) cost, c_b is the buyer's unit purchase cost, I is the carrying cost dollar per dollar, and P is the manufacturer production rate (P>D). The optimal order quantity that minimizes (9) is given as

$$Q^* = \sqrt{\frac{2D(A_b + A_v)}{h_b + h_v \frac{D}{P}}} \tag{10}$$

Goyal (1988) extended the work of Banerjee (1986) by relaxing the assumption of lot-for-lot policy. He suggested that (9) should be written as

$$TC_{sc}(Q) = \frac{A_b D}{Q} + (h_b - h_v)\frac{Q}{2} + \frac{A_v D}{\lambda Q} + \frac{\lambda h_v Q}{2}\left(1 + \frac{D}{P}\right) \tag{11}$$

The optimal order quantity that minimizes (11) is given as

$$Q(\lambda)=\sqrt{\frac{2D\left(A_b+\dfrac{A_v}{\lambda}\right)}{h_b-h_v+\lambda h_v\left(1+\dfrac{D}{P}\right)}} \tag{12}$$

Joglekar & Tharthare (1990) presented the refined JELS model which relaxes the lot-for-lot assumption, and separates the traditional setup cost into two independent costs. They proposed a new approach to the problem which they claim will require minimal co-ordination between the vendor and purchasers. They believed this approach, known as the individually responsible and rational decision (IRRD) approach allows the vendor and the purchasers to carry out their individually rational decisions. Very recently, Ben-Daya et al. (2008) provided a comprehensive and up-to-date review of the JELS that also provides some extensions of this important problem. In particular, a detailed mathematical description of, and a unified framework for, the main JELP models was provided.

Wu & Ouyang (2003) determined the optimal replenishment policy for the integrated single-vendor single-buyer inventory system with shortage algebraically. This approach was developed by Grubbström & Erdem (1999) who showed that the formula for the EOQ with backlogging could be derived algebraically without reference to derivatives. Wu & Ouyang's (2003) integrated vendor–buyer total cost per year is given by

$$TC_{sc}=\frac{A_bD}{Q}+h_b\frac{(Q-B)^2}{2Q}+\pi_b\frac{B^2}{2Q}+\frac{A_vD}{\lambda Q}+h_v\frac{Q}{2}\left[\lambda\left(1-\frac{D}{P}\right)+\frac{2D}{P}-1\right]$$

Where B is the maximum shortage level for the buyer. The optimal solutions of Q and B are given as

$$Q(\lambda)=\sqrt{\frac{2D(\pi_b+h_b)\left(A_b+\dfrac{A_v}{\lambda}\right)}{h_b\pi_b+h_v(\pi_b+h_b)\left[\lambda\left(1-\dfrac{D}{P}\right)+2\dfrac{D}{P}-1\right]}}$$

$$B(\lambda)=\frac{h_b}{\pi_b+h_b}Q(\lambda)$$

Where π_b is the annual buyer's shortage cost per unit.

Ertogral et al. (2007) develop two new models that integrate the transportation cost explicitly in the single vendor single-buyer problem. The transportation cost was considered to be in an all-unit-discount format for the first model. Their supply chain cost function was of the form

$$TC_{sc}=\frac{(A_v+\lambda A_b)D}{\lambda q}+h_v\left[q\frac{D}{P}+\frac{\lambda q}{2}\left(1-\frac{D}{P}\right)\right]+(h_b-h_v)\frac{q}{2}+C_T$$

Where $C_T=c_{iD}$ is the transportation cost per unit of time and C_T is a step-form function, where $q\in[M_i,M_{i+1})$, i=0,1,2…,λ, and M_0 = 0, and q is the shipment lot size.

<u>*Non-uniform demand*</u>

Li et al. (1995) considered the case where the buyer is in monopolistic position with respect to the vendor. They assumed the demand, $D = \alpha_b p_b^{-\beta}$, by the buyer's customers is a decreasing function of the buyer's price p_b, where $\alpha_b > 0$ and $0 < \beta < 1$ that could be determined by some statistical technique from historical data. Li et al. (1995) assumed $p_b = kp$ where p is the buyer purchase price and $k > 0$, and rewriting the demand function as $D = \alpha p^{-\beta}$ where $\alpha = \alpha k^{-\beta}$. When the vendor and the buyer achieve full cooperation, the supply chain's total cost function is given

$$TC_{sc}(p,Q) = \alpha(1-G)p^{1-\beta} + \alpha(A_v + A_b)\frac{p^{-\beta}}{Q} + \frac{h_b}{2}pQ$$

Where G is the vendor's gross profit on sales. The above cost function was minimized subject to $\alpha p^{1-\beta} + \alpha A_b p^{-\beta}/Q + h_b p Q/2 \le C_0$, $p > 0$, and $Q > 0$, where C_0 is the maximum available annual investment. Then the equilibrium point of the co-operative game is

$$p^* = \left\{\frac{\eta^*}{\alpha G}\left(C_0 - \frac{\eta^* h_b A_b}{2(G-\eta^*)}\right)\right\}^{1/(1-\beta)}$$

$$Q^* = \frac{2\alpha(G-\eta^*)}{\eta^* h_b}\left(p^*\right)^{-\beta}$$

Where $\eta^* = \dfrac{G(h_b A_b + 2C_0) - \sqrt{G(h_b A_b + 2C_0)h_b(GA_b + A_v)}}{h_b A_b + 2C_0}$

Boyaci & Gallego (2002) analyzed coordination issues in a supply chain consisting of one vendor (wholesaler) and one or more buyers (retailers) under deterministic price-sensitive customer demand. They defined the total channel profits as

$$\Pi(w,\lambda,p,Q) = (p - c_v)D(p) - \left(\frac{A_v}{\lambda} + a_v + A_b\right)\frac{D(p)}{Q}$$

$$-\frac{1}{2}\left\{(I_v c_v + \theta_v)\lambda + \theta_b - \theta_v - |I_b - I_v|w\right\}Q$$

Where a_v is the vendor's fixed cost of processing a buyer's order, θ_v (θ_b) is the vendor's (buyer's) opportunity cost of the space required to store one unit of the product for one year, c_v is the vendor's unit ordering cost, and assumed to be known and constant, w is a decision variable selected by the wholesaler, $D(p)$ is the demand rate seen by the buyer when the Buyer (retailer) price is p, and I_v (I_b) the vendor's (buyer's) opportunity cost of capital per dollar per year. They investigated their model for the cases of inventory ownership ($I_v > I_b$ or $I_v < I_b$), equal ownership ($I_v = I_b$), and an arbitrage opportunity to make infinite profits ($I_v \ne I_b$).

Permissible delay in payments

Besides quantity discounts, permissible delay in payments is a common mechanism of trade credit that facilitates coordinating orders among players in a supply chain.

Jamal et al. (2000) assumed that the buyer can pay the vendor either at time some time M to avoid the interest payment or afterwards with interest on the unpaid balance due at M. Typically, the buyer may not pay fully the wholesaler by time M for lack of cash. On the other hand, his cost will be higher the longer the buyer waits beyond M. Therefore, the buyer will gradually pay the wholesaler until the payment is complete. Since the selling price is higher than the unit cost, and interest earned during the credit period M may also be used to payoff the vendor, the payment will be complete at time P before the end of each cycle T (i.e., $M \le P \le T$). Jamal et al. (2000) modelled the vendor-buyer system as a cost minimization problem to determine the optimal payment time P^* under various system parameters.

$$TC_{sc}(P,T) = \frac{A_v + A_b}{T} + \frac{cD}{\theta^2 T}\left(e^{\theta T} - 1\right)(\theta + I) - cD - \frac{IcD}{\theta} - \frac{cI_pD}{\theta^2 T}\left(e^{\theta(T-P)} - e^{\theta(T-M)}\right)$$
$$-\frac{cI_pD}{\theta T}(P-M) - I_pD(s-c)\left(P^2 - M^2\right)/2T$$
$$-I_p s I_e D M^2 (P-M)/2T - sI_eD\left(M^2 + (T-P)^2\right)/2T$$

Where I_e is the interest earned per dollar per unit time, I_p the interest paid per dollar per unit time dollars/dollar-year, I is the inventory carrying cost rate, c is the unit cost, s is the unit selling price, and θ is the deterioration rate, a fraction of the on-hand inventory. No closed form solution was developed, and an iterative search approach is employed simultaneously to obtain solutions for P and T. Recently, Yang & Wee (2006a) proposed a collaborative inventory model for deteriorating items with permissible delay in payment with finite replenishment rate and price-sensitive demand. A negotiation factor is incorporated to balance the extra profit sharing between the two players.

Abad & Jaggi (2003) considered a vendor–buyer channel in which the end demand is price sensitive and the seller may offer trade credit to the buyer. The unit price seller charged by the seller and the length of the credit period offered by the vendor to the buyer both influence the final demand for the product. The paper provides procedures for determining the vendor's and the buyer's policies under non-cooperative as well as cooperative relationships. Here, we present the model for the cooperative case. Abad & Jaggi (2003) used Pareto efficient solutions that can be characterized by maximizing (Friedman, 1986)

$$Z = \mu\left[Kp^{-e}\left(c_b - c_v - I_v c_b M - \frac{A_v}{Q}\right)\right] + (1-\mu)\left[Kp^{-e}\left(p - c_b(1 - I_c M) - \frac{A_b}{Q}\right) - \frac{Ic_bQ}{2}\right]$$

Where $D(p) = Kp^{-e}$ is annual demand rate as a function of the buyer's price, e the index of price elasticity, M is the credit period (vendor's decision variable), c_b the price charged by the vendor to the buyer, c_v is the seller's unit purchase cost, I_{cb} vendor's opportunity cost of capital, I_c short-term capital cost for the buyer, I_b inventory carrying charge per year excluding the cost of financing inventory, and $I = I_c + I_b$. The first order necessary condition for maximizing Z with respect to c_b yields

$$0 \le \mu = \frac{1 - I_c M + IQ/\left(2Kp^{-e}\right)}{2 - I_v M - I_c M + IQ/\left(2Kp^{-e}\right)} \le 1$$

First order conditions with respect to Q and M yield

$$Q = \sqrt{\frac{2Kp^{-e}\left[\mu A_v + (1-\mu)A_b\right]}{(1-\mu)Ic_b}}$$

$$M = \frac{(1-\mu)I_c - a\mu}{2b\mu}$$

where $I_v = a + bM$, $a > 0$, $b > 0$. Abad & Jaggi (2003) cautioned that not all μ in the interval [0,1] may yield feasible solutions.

Jaber & Osman (2006) proposed a centralized model where players in a two-level (vendor–buyer) supply chain coordinate their orders to minimize their local costs and that of the chain. In the proposed supply chain model the permissible delay in payments is considered as a decision variable and it is adopted as a trade credit scenario to coordinate the order quantity between the two-levels. They presented the buyer and vendor unit time cost functions respectively as

$$TC_b(Q,t,\tau) = \frac{A_b D}{Q} + c_b D + \frac{D}{Q} H_b(Q,t,\tau) + \frac{s_b}{2} Q + c_b D(e^{k_v(\tau - t)} - e^{k_b \tau})$$

where $H_r(Q,t,\tau) = h_b(Q - Dt)^2 / 2D$ (Case I), or $h_b(Q - D\tau)^2 / 2D$ (Case II), or 0 (Case III). It should be clarified that the retailer must settle his/her balance, $c_b Q$, with the supplier either by time t or by time τ, which are respectively the *interest-free* and the interest permissible delay in payment periods, where $0 \le H_b(Q,t,\tau) \le h_b Q^2 / 2D$

$$TC_v(Q,\lambda,t,\tau) = \frac{A_v D}{\lambda Q} + \frac{h_v + s_v}{2} Q(\lambda - 1) + h_v \tau D + (c_b - c_v) De^{k_v t} - c_b De^{k_v(\tau - t)} + c_v D$$

Define t as the permissible delay in payment in time units, (interest-free period), and τ is the buyer's time to settle its account with the vendor. If $\tau > t$ the supplier charges interest for the period of $\tau - t$ (interest period). The other parameters are defined as follows (where $i = v, b$): k_i, the return on investment, h_i is holding cost per unit of time, representing the cost of capital excluding the storage cost, s_i the storage cost per unit of time at level i excluding the holding cost, and c_i = Procurement unit cost for level $i = v, b$. With coordination, the buyer and the vendor need to agree on the following decision variables Q, λ, t, and τ, that minimizes the total supply chain cost by solving the following mathematical programming model

Minimize $\quad TC_{sc}(Q,\lambda,t,\tau) = TC_v(Q,\lambda,t,\tau) + TC_b(Q,t,\tau)$

Subject to:

$\tau - t \geq 0$
$\lambda \geq 1$
$Q/D - t \geq 0$ (Case I), $Q/D - \tau \geq 0$ (Case II), $\tau - Q/D \geq 0$ (Case III)
$t \geq 0$, $\tau \geq 0$, λ=1, 2, 3,.., and $Q \geq 1$

Jaber & Osman (2006) assumed profits (savings) from coordination to be shared between the buyer and the vendor in accordance with some prearranged agreement.

Chen & Kang (2007) considered a similar model to that of Jaber & Osman (2006), where they investigated their model for predetermined and extended periods of delay in payments. However, and unlike the work of Jaber & Osman (2006), Chen & Kang (2007) have not treated the length of delay in payment as a decision variable. Sheen & Tsao (2007) consider vendor-buyer channels subject to trade credit and quantity discounts for freight cost. Their work determined the vendor's credit period, the buyer's retail price and order quantity while still maximizing profits. Sheen & Tsao (2007) focused on how channel coordination can be achieved using trade credit and how trade credit can be affected by quantity discounts for freight cost. Like Chen & Kang (2007), they set an upper and lower bounds on the length of the permissible delay in payments. They search for the optimal length of this credit from the vendor's perspective and not from that of the supply chain coordination.

Multiple buyers

Affisco et al. (1993) provided a comparative analysis of two sets of alternative joint lot-sizing models for the general one-vendor, many-nonidentical buyers' case. Specifically, the basic joint economic lot size (JELS) and individually responsible and rational decision (IRDD) models, and the simultaneous setup cost and order cost reduction versions are explored. The authors considered co-operation is required of the parties regardless of which model they choose to implement, it is worthwhile to investigate the possible impact of such efforts on the model. The joint total relevant cost on all buyers and the vendor is given by

$$TC_{sc} = \sum_{i=1}^{n} \left\{ \left(\frac{D_i}{Q_i} \right) \left(A_{b,i} + \alpha \right) + h_{b,i} \frac{Q_i}{2} \right\} + h_v \frac{Q_v}{2} \left(1 - \frac{D}{P} \right) + A_v \frac{D}{Q_v}$$

Where α is the vendor's cost of handling and processing an order from a purchaser. This included such costs as inspection, packing and shipping of an order, and the cost of any related paperwork, but not the cost of manufacturing setup to produce a production quantity. The refined JELS model results from minimizing TC which yields the following relationships for the vendor's and *i*th buyer's joint optimal lot sizes are $Q_v^* = \sqrt{2DA_v / \left(h_v (1 - D/P) \right)}$, and $Q_i^* = \sqrt{2D_i (A_{b,i} + \alpha) / h_{b,i}}$ respectively, where $D = \sum_{i=1}^{n} D_i$. Under the IRRD model, since a purchaser must pay for the vendor's handling costs every time it orders $O_i = (D_i / Q_i)(A_{b,i} + \alpha)$.The holding cost per unit per unit time is also reduced due to the transferred handling costs.

Lu (1995) considered an integrated inventory model with a vendor and multiple buyers. Lu assumed the case where the vendor minimizes its total annual cost subject to the maximum cost that the buyer may be prepared to incur. They presented a mixed integer programming problem of the form

$$\text{Minimize} \quad TC_{sc}(T, k_i \mid i = 1, \ldots, n) = \frac{1}{T}\left(A_v + \sum_{i=1}^{n} \frac{A_{b,i}}{\max\{1, k_i\}} \right)$$

$$+ \frac{T}{2}\sum_{i=1}^{n} \max\{1, k_i\} h_{b,i} D_i \left(1 + \min\{1, k_i\} - \frac{D_i}{P_i} - \frac{2m_i}{k_i} \right)$$

Subject to

$$T \geq 0,$$

$$\frac{1}{2}\left(\frac{T_i^*}{k_i T} + \frac{k_i T}{T_i^*} \right) \leq B_i$$

$$k_i \in \{1,2,3,\ldots\} \cup \left\{ \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \ldots \right\}$$

$$m_i = \lfloor k_i (1 - D_i / P_i) \rfloor, \; i = 1,2,\ldots,n$$

Where $T_i^* = \sqrt{2A_{b,i}/(h_{b,i} D_i)}$, $A_{b,i}$, $h_{b,i}$, and D_i are respectively the optimal cycle time, order cost, holding cost, and demand for buyer *i*. *T* is the order interval suggested by the vendor and $B_i > 1$ is some threshold value. Lu (1995) considered a quantity discount schedules to maximize the vendor's total profit subject to the maximum cost that the buyer may be prepared to incur. Yao & Chiou (2004) proposed an efficient heuristic which solves Lu's model by exploring its optimality structure. They observed that the vendor's optimal annual total cost function is a piece-wise convex curve with respect to the vendor's production setup interval. Yao & Chiou (2004) proposed an effective heuristic that out-performs Lu's heuristic.

Goyal (1995) commented on the work of Lu (1995) and suggested a joint inventory cost function of the form

$$TC_{sc}(k) = \frac{D(A_v + kA_b)(n-1)}{q_1(n^k - 1)} + \frac{q_1}{2}\left(h_b + \frac{h_v}{k} \right)\frac{n^k + 1}{n+1}$$

Where *k* is the number of shipments in which the entire lot of size $Q = q_1(n^k - 1)/(n-1)$ is transported by the vendor to the buyer in shipments of size q_i, where *i* = 1, 2, …, *k*. Assuming that the ratio between the $(i+1)$-*st* shipment and the *i*-th shipment is equal to *n*. For a particular value of *k*, the economic value of $q_1 = q(k)$ and the minimum joint total annual costs are given respectively as

$$q(k) = \sqrt{\frac{2D(A_v + kA_b)(n^2 - 1)}{\left(n^{2k} - 1\right)\left(h_b + \dfrac{h_v}{2} \right)}}$$

$$TC_{sc}(q(k)) = \sqrt{\frac{2D(h_b + h_v/2)(n-1)(n^k+1)(A_v + kA_b)}{(n+1)(n^k-1)}}$$

The works of Lu (1995) and Goyal (1995) are further analyzed in Hill (1997) and Viswanathan (1998).

Chen et al. (2001) proposed a coordination model for a centralized two-echelon system whose profit function is given as

$$\Pi = \sum_{i=1}^{n}\left[(p_i(D_i) - c_v - c_{b,i})D_i - \Psi(D_i) - \frac{A_{b,i}}{T_i} - \frac{1}{2}h_v D_i \max\{T_v, T_i\} - \frac{1}{2}h_{b,i}D_i T_i \right] - \frac{A_v}{T_v}$$

Where p_i retail price charged by buyer i, $p_i(D_i)$ annual demand a decreasing function of the retail price, $c_{b,i}$ unit shipping cost to from the vendor to the buyer $\Psi(D_i)$ is the annual cost incurred by the vendor for managing buyer i's account with $\Psi(\cdot)$ being a nondecreasing and concave where $\Psi(0)=0$, T_i is the replenishment interval for buyer i, and T_v is the replenishment interval for the vendor.

Viswanathan & Piplani (2001) proposed a supply chain model of coordinating supply chain inventories through the use of common replenishment epochs (CRE) or time periods. They considered a vendor and multiple buyers with a single product. With the CRE strategy, the vendor specifies that the buyers can only place orders at specific points in time. The vendor was assumed to insist that the replenishment interval for each buyers i T_i^* should be an integer multiple of the common replenishment period $T = \lambda_i T_i^*$, where λ_i is a positive integer. With the specification of the CRE, the buyers' flexibility is reduced and inventory costs increased. The vendor will need to provide a price discount Z_i to compensate buyer i for inventory cost increase. The problem of determining the T and Z for the vendor can then be formulated as follows

$$\text{Minimize } TC_{sc} = \frac{A_v}{T} + \sum_{i=1}^{n}\left(D_i Z + \frac{a_i}{\lambda_i T} \right)$$

Subject to:

$$D_i Z \geq \frac{A_{b,i}}{\lambda_i T} + h_{b,i}\lambda_i T - 2(1-S)\sqrt{A_{b,i}h_{b,i}}, \quad i = 1,\ldots,n$$

$$T \in \mathbf{X}$$

$$\lambda_i \geq 1 \text{ and integer, } i = 1,\ldots,n$$

Where $\mathbf{X} = \{1/365, 1/52, 2/52, 1/12, 2/12, 1/4\}$, a_i is the cost of processing the order of buyer i, S being the percentage savings, and $D_i Z$ is the total dollar discount offered to buyer i. Further investigation of the work of Viswanathan & Piplani (2001) is provided in Piplani & Viswanathan (2004).

Woo et al. (2001) extended upon the work of Woo et al. (2000) to account for the case of multiple buyers. They assumed that vendor and all buyers are willing to invest in reducing the ordering cost (e.g., establishing an electronic data interchange based inventory control system) in order to decrease their joint total cost. Woo et al. (2001) stressed that a major managerial implication from this ordering cost reduction is that the efforts to streamline and speedup transactions via the application of information technologies may result in a higher degree of coordination and automation among allied trading parties. Woo et al. (2001) also assume that shortages are not allowed for the vendor and that the information of buyers' replenishment decision parameters is available to the vendor. The joint total cost for the vendor and all the buyers per unit time is

$$TC_{sc} = K + \frac{1}{T}\left[\frac{A_v}{\lambda} + S_v + \sum_{i=1}^{n} T_i(K)\right] + \frac{T}{2}\left[uh_{v,m}\sum_{i=1}^{n} D_i\left(\lambda - 1 + \frac{\sum_{i=1}^{n} D_i}{P}\right)\right.$$

$$\left. + \frac{h_{v,p}}{P}\sum_{i=1}^{n} D_i^2 + \sum_{i=1}^{n} h_{b,i}(1-f_i)^2 D_i + \sum_{i=1}^{n} L_i f_i^2 D_i\right]$$

Where K is expenditure per unit time to operate the planned ordering system between vendor and all buyers, which is a decision variable, and $T_i(K)$ is the planned ordering cost per buyer i's order, which is a strictly decreasing function of K with $T_i(0) = T_{0,i}$ and $T_i(K_0) = 0$, T is the common cycle time for buyers, which is a decision variable, u is usage rate of raw materials for producing each finished item, $h_{v,m}$ and $h_{v,p}$ are respectively the vendor's carrying cost per unit of raw materials and finished products, $h_{b,i}$ is the carrying cost per unit held per unit time for buyer i, f_i is the fraction of backlogging time in a cycle for buyer i, which is a decision variable, and L_i is the backlogging cost per unit backlogged per unit time for buyer i. Note that this paper assumes the vendor incurs ordering cost for raw material A_v and a setup cost per production run for vendor S_v.

Recently, Yu et al. (2006) improved upon the work of Woo et al. (2001) by providing a lower or equal joint total cost as compared to the relaxation of their integral multiple material ordering cycle policy to a fractional-integral multiple material ordering cycle policy. More recently, Zhang et al. (2007) extended the work of Woo et al. (2001) by relaxing the assumption of a common cycle time for all buyers and the vendor.

Siajadi et al. (2006a,b) presented a methodology to obtain the Joint Economic Lot size in the case where multiple buyers are demanding one type of item from a single vendor. The shipment policy is found and a new model is proposed to minimize the joint total relevant cost (JTRC) for both vendor and buyer(s). Further it is shown that a multiple shipment policy is more beneficial than a single shipment policy considered by Banerjee (1986). The incurred saving is increasing as the total demand rate approaches the production rate. This means that as long as the first assumption is still satisfied, the better the production capacity is utilized, the greater the saving will be. Conversely, when the dominating cost is the transportation cost, the saving is decreasing as the numbers of shipment approach to one.

Consequently, the new model becomes identical with the traditional model, as the numbers of shipment are equal to one.

Yang & Wee (2006b) considered a pricing policy for a two-level supply chain with a vendor and multiple buyers. Three scenarios are discussed. The first scenario neglects integration and quantity discount. The second scenario considers the integration of all players without considering quantity discount. The last scenario considers the integration and the quantity discount of all players simultaneously. The total supply chain cost for scenario i =1,2,3 was of the form

$$TC_{sc,i} = \frac{D\left(A_v + \lambda_i a_v\right)}{\lambda_i \sum_{j=1}^{n} Q_{i,j}} + \frac{h_v}{2}\sum_{j=1}^{n} Q_{i,j}\left[(\lambda_i - 1)\left(1 - \frac{D}{P}\right) + \frac{D}{P}\right] + \sum_{j=1}^{n}\left(c_{b,1,j} - c_{b,i,j}\right)D_j$$

$$+ \sum_{j=1}^{n}\frac{D_j A_{b,j}}{Q_{i,j}} + \sum_{j=1}^{n}\frac{Q_{i,j} h_{b,i,j}}{2} - \sum_{j=1}^{n}\left(c_{b,1,j} - c_{b,i,j}\right)D_j$$

Where $D = \sum_{j=1}^{n} D_j$ total demand rate of all buyers with D_j being the demand for buyer j, A_v and $A_{b,j}$ are as defined earlier respectively the vendor's and buyer's j order/setup costs, a_v a fixed cost to process buyer's order of any size, λ_i the number of deliveries from vendor to each buyer per cycle for scenario i, $Q_{i,j}$, the order quantity for buyer j for scenario i, h_v is the vendor's holding cost, $h_{b,i,j}$ is the buyer's holding cost for buyer j for scenario i, and $c_{b,i,j}$ being the unit purchase cost for buyer j for scenario i. Recently, Wee & Yang (2007) proposed a very similar work to that of Yang and Wee (2006b), where they extended the work of Yang et al. (2007) to consider multiple buyers rather than a single buyer. They developed an optimal pricing and replenishment policy in a "leagile" (lean and agile) supply chain system for an integrated vendor-buyers system considering JIT concept and price reduction to the buyers for ordering larger quantity.

Yugang et al. (2006) considered a Vendor-Managed-Inventory (VMI) supply chain, which consists of one vendor (manufacturer) and multiple different buyers (retailers) with a single product. The vendor produces a single product with a limited production capacity and distributes it to its buyers. Each buyer buys the product from the manufacturer at wholesale price, and then sells it to the consumer market at a retail price. The buyer' markets are assumed to be dispersed and independent of each other. In the proposed supply chain, the vendor, as a leader, determines the wholesale price and inventory policy for the supply chain to maximize its own profit, and each retailer, as a follower, in turn takes the vendor's decision results as given inputs to determine the optimal retail prices to maximise its own profits. Along this line of research, Nachiappan et al. (2006) proposed a methodology to determine the common optimal price (contract and selling prices) that protects the profit of the buyer which is the main reason for the existence of partnership, for maximum channel profit in a two-echelon SC to implement VMI.

Multiple Items
Kohli & Park (1994) examined joint ordering policy in a vendor-buyer system as a method for reducing the transactions cost for multiple products sold by a seller to a homogeneous group of buyers. They found that efficient joint lot-sizes are independent of prices, and are supported by a range of average-unit prices that permit every possible allocation of the transactions-cost saving between the buyer and the seller. Kohli & Park (1994) also found that product bundling supports efficient joint orders across products, just as a quantity discount supports efficient transactions for a single product.
Chen & Chen (2005a) proposed both centralized and decentralized decision policies to analyze the interplay and investigate the joint effects of two-echelon coordination and multi-product replenishment on reduction of total costs. The total joint cost was given as

$$TC_{sc}(\{\lambda_i\},T)=\frac{A_b}{T}+\sum_{i=1}^{k}\left[\frac{a_{b,i}}{T}+\frac{T}{2}\left(h_{b,i}D_i\right)\right]$$

$$+\frac{A_v}{T}+\sum_{i=1}^{k}\left[\frac{a_{v,i}}{T}+\frac{T}{2}\left(\frac{h_{v,i}D_i^2}{P_i}\right)+\frac{a_{r,i}}{\lambda_i T}+\frac{u_i h_{r,i}T}{2}\left(\frac{D_i^2}{P_i}+(\lambda_i-1)D_i\right)\right]$$

Where T is the common cycle, $T>0$, D_i the demand rate of finished item i, P_i the production rate of finished item i produced by the vendor ($P_i > D_i$), $h_{b,i}$ is the inventory holding cost of finished item i per unit time for the buyer, $h_{v,i}$ is the inventory holding cost of finished item i per unit time for the vendor, $h_{r,i}$ the inventory holding cost of raw material for finished item i per unit time for the vendor, $a_{b,i}$ the minor setup cost for adding finished item i into the order for the buyer, $a_{v,i}$ the minor setup cost for adding finished item i into the production schedule for the vendor, $a_{r,i}$ the ordering cost of raw material for finished item i per lot for the vendor, u_i usage rate of raw material for the end item i produced by the manufacturer, and k is the total number of items. The optimal integer multiple of the common replenishment cycle for the raw material, the optimal common replenishment cycle, and the optimal order quantity for each item are given respectively as

$$\lambda_i^*=\left\lceil -\frac{1}{2}+\frac{1}{2}\sqrt{1+\frac{8a_{r,i}}{T^2u_ih_{r,i}D_i}}\right\rceil$$

$$T^*=\sqrt{\frac{2\left[A_b+A_v+\sum_{i=1}^{k}\left(a_{b,i}+a_{v,i}+\frac{a_{r,i}}{\lambda_i^*}\right)\right]}{\sum_{i=1}^{k}\left[h_{b,i}D_i+\frac{h_{v,i}D_i^2}{P_i}+u_ih_{r,i}\left(\frac{D_i^2}{P_i}+\left(\lambda_i^*-1\right)D_i\right)\right]}}$$

$$Q_i^* = \sqrt{\frac{2D_i^2\left[A_b + A_v + \sum_{i=1}^{k}\left(a_{b,i} + a_{v,i} + \frac{a_{r,i}}{\lambda_i^*}\right)\right]}{\sum_{i=1}^{k}\left[h_{b,i}D_i + \frac{h_{v,i}D_i^2}{P_i} + u_i h_{r,i}\left(\frac{D_i^2}{P_i} + \left(\lambda_i^* - 1\right)D_i\right)\right]}}$$

Chen & Chen (2005 b,c) proposed several optimization models adopting the joint replenishment program and channel coordination practice for a three level inventory system. The main purpose behind these models is to investigate how they influence possible supply chain improvements. The works of Chen & Chen (2005b,c) neither considered marketing stimulus into account, nor they assumed that the goods being imperishable for the period of production and selling. Furthermore, they dealt with cost-minimization supply chain design.

Chen & Chen (2007) focused on an area of emerging research: managing a multi-product and multi-echelon supply chain which produces and sells deteriorating goods in the marketplace. They formulated four profit-maximization models by considering the effects of channel coordination and a joint replenishment program on the supply-side cost control, taking into account the effect of the pricing scheme on demand and revenue increment. In addition, a profit-sharing mechanism via target rebates has been proposed, leading to Pareto improvements among channel participants.

Product/process Quality

Huang (2002) investigated the model of Salameh and Jaber (2000) in an integrated vendor-buyer context, where imperfect items at the buyer's end are withdrawn from inventory as a single batch and sold at a discounted price.The total annual cost of the vendor-buyer

$$TC_{sc}(\lambda, Q) = \left\{\frac{(A_v + A_b)D}{\lambda Q} + \frac{FD}{Q} + (d + W)D + \frac{DQ(h_b - h_v)}{x}\right\}E\left[\frac{1}{1-\gamma}\right] - WD$$

$$+\left\{\frac{DQ}{P} + \frac{\lambda Q}{2}\left(1 - \frac{D}{P}\right)\right\}h_v - \frac{DQ}{x}(h_b - h_v) + \frac{Q(1 - E[\gamma])}{2}(h_b - h_v)$$

Where F is the transportation cost per delivery, γ is the percentage of defective items whose probability density function is $f(y)$, x is the screening rate per unit ($x > D$), d is the unit screening cost, and W is the vendor's unit warranty cost of a defective item. The optimal order quantity that minimizes the above equation was given as

$$Q(\lambda) = \sqrt{\frac{2D\left[\frac{A_v + A_b}{\lambda} + F\right]E\left[\frac{1}{1-\gamma}\right]}{\left[\frac{2D(h_b - h_v)}{x}\right]\left(E\left[\frac{1}{1-\gamma}\right] - 1\right) + \left[\frac{2D}{P} + \lambda\left(1 - \frac{D}{P}\right)\right]h_v + (1 - E[\gamma])(h_b - h_v)}}$$

Khouja (2003a) considers a simple supply chain consisting of a vendor who produces a product and delivers it to a buyer who in turn sells it to the final customer. He assumed the lot size quality relationship to follow that of Porteus (1986). Porteus assumed the production process to be functioning perfectly at the start of production. With the production of each unit, the process may shift out-of-control with a constant known transition probability, and start producing all defective units. Once the process is out of control, it stays that way while the remainder of the lot is produced. The production system is restored to perfect quality when it is set up again. Porteus (1986) estimated the expected defectives per lot to be $\rho Q^2/2$, where ρ is the probability of the process going out of control and ρ is very small (Khouja, 2005). The expected total annual cost for the vendor and the buyer is

$$TC_{sc} = \left(A_b + \frac{A_v}{\lambda}\right)\frac{D}{Q} + \left[h_b - h_v + h_v\lambda\left(1 + \frac{D}{P}\right)\right]\frac{Q}{2} + \frac{1}{2}\rho\lambda QDw$$

Where λ is, as defined earlier, the vendor's lot-size multiplier (positive integer) of the buyer's order quantity Q, and w being the cost to rework a defective unit. Minimizing the expected total annual cost for the whole supply chain (i.e. joint optimization), then the optimality conditions are given by

$$\lambda^*\left(\lambda^* - 1\right) \le \frac{(h_b - h_v)A_v}{A_b\left(Dw\rho + (1 + D/P)h_v\right)} \le \lambda^*\left(\lambda^* + 1\right)$$

$$Q^*(\lambda) = \sqrt{\frac{2(\lambda A_b + A_v)}{\lambda\left[\lambda w\rho + h_b/D + (\lambda/P + (\lambda - 1)/D)h_v\right]}}$$

Khouja (2003a) also investigated his model for the cases when the vendor has a constant failure rate, and when demand is stochastic.

Similar to Huang (2002), Goyal et al. (2003) considered a two-level supply chain where there is a vendor and a buyer for a single product, where the number of perfect units is at least equal to the demand during the screening time and that the defective units are sold as a single batch at the end of the screening period (Salameh & Jaber, 2000). Their expected annual cost was given as

$$TC_{sc}(\lambda, Q) = (A_v + A_b + \lambda F)\frac{D}{Q} + \frac{Q}{2\lambda}\left\{[1 + (\lambda - 2)(1 - D/P)]h_v + \frac{h_b}{E[1/(1-\gamma)]}\right\}$$

Where F is the transportation cost per shipment, γ is the percentage of defective items, a random variable, and $E[1/(1-\gamma)] = \int_0^\infty f(y)dy$ is the expected value with $f(y)$ being the probability density function of γ. The optimal order quantity that minimizes the above equation is

$$Q(\lambda) = \sqrt{\frac{2\lambda(A_v + A_b + \lambda F)D}{[1 + (\lambda - 2)(1 - D/P)]h_v + h_b/E[1/(1-\gamma)]}}$$

A very similar model to that of Goyal et al (2003) was developed in Huang (2004). Siajadi et al. (2005) analysed scenario is that a single buyer (or a group of buyers), demand(s) a particular type of end/finished item where back-order is not allowed. The delivery of the finished item to the customer is based on multiple small deliveries of equal size, Q, instead of a lot-for-lot basis. They assumed that the production of the finished item will include the production of imperfect quality items, where 100% inspection is performed for each lot at a constant unit cost. They further assumed that a lot contains a percentage of defectives with a known probability distribution function where the defective items are reworked instantaneously at a cost and kept in stock. Reworked items are considered as-good-as-new. The total unit time supply chain cost was given as

$$TC_{sc} = \frac{A_v + A_v' + \sum_{i=1}^{k} a_i/\lambda_i}{T} + \frac{T}{2}D'\left[\sum_{i=1}^{k} h_i u_i\left(\frac{D'}{P} + \lambda_i - 1\right) + h_v\left(\frac{D}{P} + E\right)\right] - \frac{q}{2}h_v$$

where A_v' is the major setup cost for ordering raw materials for every cycle period, a_i is the minor order (setup) cost for ordering each type of raw material, T is the cycle time, h_i the vendor's holding cost for raw material i, u_i is usage rate of raw material for producing finished item i, E represents the expected percentage of good items, D' is the actual demand rate considering the rejected items, λ_i is the integer multiple of the basic cycle period for each replenished item, and q is equal freight quantity of finished item to customers. The stationary points in the T direction were found to occur when

$$T = \sqrt{\frac{2\left(A_v + A_v' + \sum_{i=1}^{k} a_i/\lambda_i\right)}{D'\left[h_v(D/P + E) + \sum_{i=1}^{k} h_i u_i\left[D'/P + \lambda_i - 1\right]\right]}}$$

Comeaux & Sarker (2005) addressed the shortcomings within existing models that would result in implementation problems for practical and industrial applications. Specifically, the fraction conforming in the quality-adjusted optimal batch size model denominator is squared to accurately reflect the quality improved and set-up cost reduction model's effectiveness. They also expanded the joint economic lot size models to address the full range of 0–100% product quality inspections by multiplying the fraction inspected by the inspection cost. The authors added that these models were modified to account for the cost of scrap generation by separating the proportion of non-conforming product that requires disposal and multiplying that quantity by the disposal cost. Moreover, the effects of rejecting conforming product, as well as accepting non-conforming product, in the quality inspection processes were also addressed.

El Saadany & Jaber (2008) investigated the work of Khouja (2005) in a centralized decision model where players in a two-level (vendor–buyer) supply chain coordinate their orders to minimize their local costs and that of the chain. Unlike Porteus (1986), Khouja (2005) assumed that if the process is interrupted to perform corrective action to restore the process back in control reduces the number of defects generated. This reduces reworks significantly but at an additional cost of increased minor setups. For this assumption, three possible behaviours, or cases, of the vendor's inventory level were depicted with corresponding cost models developed. Case 1 assumes that restoring the production process after delivering a lot to the buyer. Case 2, restoring the production process before delivering a lot to the buyer. Case 3, restoring the production process at any time. El Saadany and Jaber (2008) developed mixed integer nonlinear programming models to optimize coordination for the three cases. The mathematics for the three cases presented in El Saadany and Jaber (2008) are lengthy and therefore we refrain from presenting them herein.

Deterioration

Lin & Lin (2004) developed an integrated vendor-buyer model for the case of product deterioration, partial backordering and constant service level, where deterioration occurs at the buyer's side only. It was assumed that the vendor invests heavily to build facilities that keep product fresh and therefore no deterioration. They assumed that transportation time of goods is short.

Lin & Lin (2007) were concerned with the collaboration between a supplier and a buyer and take into consideration the deterioration property and complete back-ordering. Their model is similar to that of Balkhi's (1999) but assuming the vendor is a manufacturer rather than a materials supplier, and thus the buyer is a retailer (customer), or wholesaler rather than a manufacturer.

Entropy cost

There is no doubt that the proper estimation of the EOQ model input parameters, which are the order cost, carrying (holding) cost and the demand rate, are essential for producing reliable results. However, properly estimating and monitoring these costs is often not an easy task. Furthermore, the order and holding costs are aggregated costs that often include those costs that can be estimated, and exclude those which are difficult to ascertain. For example, the order cost might include costs for transportation, loading and unloading, inspection, insurance, administrative time, etc. The holding cost can include opportunity cost of capital, and costs for storage, obsolescence, damage, deterioration, insurance, etc. Furthermore, the use of more environmentally friendly materials and manufacturing processes to reduce pollution and energy expenditure give rise to additional costs that may be difficult to estimate. To address this problem, Jaber et al. (2004) postulated accounting for an additional and unavoidable cost, which we refer to as the entropy cost, when analysing EOQ systems. They postulated that the behaviour of production systems very much resembles those of physical systems. Such a parallel suggests that improvements to production systems may be achievable by applying the first and second laws of thermodynamics to reduce system entropy (or disorder).

Jaber et al. (2004) modelled commodity flow (demand rate) as a heat flow. To illustrate and briefly, when a force is imposed on a system, the system goes through a change in its state and a certain flow ensues. If, in the production system, the price is changed (lowered) from its equilibrium value, then a flow of the commodity in question may ensue. The force is what is commonly called in economics a "market force". Thus it is postulated that there will be a flow of commodity between the system and its surroundings (e.g., from the retailer to the market) at the rate

$$q(t) = -K(P(t) - P_0(t))$$

where K represents the change in the flux for a change in the price of a commodity, and is measured in units per year per dollar, $P(t)$ is the firm's price function (analogous the system's temperature), and $P_0(t)$ is the equilibrium price function (analogous the surrounding's temperature). Note that at t = 0, $P(0)$ and $P_0(0)$ register their highest values, while at $t = \tau$, $P(\tau)$ and $P_0(\tau)$ register their lowest values. The total demand in a cycle of length T, $d(T)$, is given from the above commodity flow equation as

$$d(T) = \int_0^T q(t)dt = \int_0^T -K(P(t) - P_0(t))dt$$

where $d(T)$ is measured in units, and it represents the lot size quantity; i.e., $Q = DT$. Similarly, the total entropy generated in a cycle of length T, $\sigma(T)$, is given (from thermodynamics) as

$$\sigma(T) = \int_0^T \dot{S}_{gen}(t)dt = \int_0^T K\left(\frac{P(t)}{P_0(t)} + \frac{P_0(t)}{P(t)} - 2\right)dt$$

where $\sigma(T)$ is measured in the total entropy generated over T (with $\dot{S}_{gen}(t)$ being the entropy generation rate) is measured in the same units as K. Then the entropy cost per cycle, $E(T)$, is given by dividing

$$E(T) = \frac{d(T)}{\sigma(T)} = \frac{\int_0^T -K(P(t) - P_0(t))dt}{K\int_0^T \left(\frac{P(t)}{P_0(t)} + \frac{P_0(t)}{P(t)} - 2\right)dt}$$

Jaber et al. (2006a) applied the concept of entropy cost in a two-level (vendor-buyer) supply chain to account for the hidden costs and difficult to estimate costs of an inventory system. They assumed a two-level supply chain with a finite planning horizon. In their model, a supplier's cycle has λ retailer's cycles, where λ is a positive integer. If the retailer orders n times a year, then the vendor has m replenishment cycles a year, where $m\lambda = n$ and m like λ is a positive integer. Since the vendor demand flow is a stepped function, the vendor's commodity flow is written as

$$q_v(t) = -K_v\left(P_v(t) - P_{0,v}(t)\right)$$

where $P_v(t)$ and $P_{0,v}(t)$ are respectively the vendor's commodity and equilibrium price functions, and K_v is similar in definition to K (later referred to by K_b where the subscript b indicate the buyer) where $K_v = -q_v(0)/\left(P_v(0) - P_{0,v}(0)\right)$. The entropy generated in the jth vendor's cycle that has λ buyer's cycles was given as

$$\sigma_{v,j}(\lambda, n) = \sum_{i=1}^{\lambda} K_v\left\{\frac{P_v(t)}{P_{0,v}(t)} + \frac{P_{0,v}(t)}{P_v(t)} - 2\right\} = \sum_{i=1}^{\lambda} K_v\left\{\frac{P_v(i,j,\lambda,n)}{P_{0,v}(i,j,\lambda,n)} + \frac{P_{0,v}(i,j,\lambda,n)}{P_v(i,j,\lambda,n)} - 2\right\}$$

where $i = 1,2,\ldots,\lambda$, $j = 1,2,\ldots,m$ and $T = \tau/n$. The entropy cost of the jth vendor's cycle was given

$$E_{v,j}(\lambda, n) = \frac{Q\lambda}{\sigma_{v,j}(\lambda, n)}$$

The total supply chain cost is given as

$$T_{sc}(\lambda, n) = nA_b + h_b\frac{D\tau^2}{2n} + \sum_{j=1}^{n/\lambda} E_{b,j}(\lambda, n) + \frac{n}{\lambda}A_v + \frac{h_v}{2}(\lambda - 1)D\frac{\tau^2}{n} + \sum_{j=1}^{n/\lambda} E_{v,j}(\lambda, n)$$

Stochastic models
Sharafali & Co (2000) presented some stochastic models of cooperation between the supplier and the buyer. Their study showed that only the supplier benefits from such cooperation. Sharafali & Co (2000) considered some cooperative strategies. These include the analysis of the impact of (1) price changes, (2) discount policies and (3) partial deliveries. They assumed there is a buyer or a retailer who orders from a supplier, demand at the buyer is random and is distributed as Poisson with mean rate μ, instantaneous replenishment, non-zero but constant lead time, stock outs at the buyer are back-ordered, and the buyer follow (R,Q) policy.

$$TC_{sc} = \frac{\mu}{Q}\left(A_b + \frac{A_v}{\lambda}\right) + \frac{1}{Q}\int_R^{R+Q} U(y)dy + \frac{h_v}{2}(\lambda - 1)Q$$

Where μ is the mean demand rate at the buyer's end, Demand at the buyer is random and is distributed as Poisson with mean rate μ. $U(y)$ is the rate at which the expected inventory costs accumulate at time t + Lead-time.
Pan & Yang (2002) presents an integrated inventory model with controllable lead time. The model is shown to provide a lower total cost and shorter lead time compared with those of Banerjee (1986) and Goyal (1988), and is useful for practical inventory problems. They assumed a demand X during lead time L follows a normal distribution with mean μL and standard deviation $\sigma\sqrt{L}$, the lead time has n components and these are crashed one component at a time starting with the one with the least crashing cost per unit time, and so on, and that the reorder point (ROP) equals the sum of the expected demand during lead time and the safety stock, where $ROP = \mu L + k\sigma\sqrt{L}$ and where k is known as the safety factor

$$ETC_{sc}(Q,L,\lambda) = \frac{D}{Q}\left[A_b + \frac{A_v}{\lambda} + R(L)\right] + \frac{Q}{2}\left\{\left[\lambda\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right]h_v + h_b\right\} + h_b k\sigma\sqrt{L}$$

Where $R(L) = c_i\left(L_{i-1} - L\right) + \sum_{j=1}^{i-1} c_j\left(b_j - a_j\right)$ is the lead time crashing cost, and c_i is the crashing cost per unit time for lead time component i with a_i and b_i being the minimum and maximum durations respectively, such that $\sum_{i=1}^{n} a_i \le L \le \sum_{i=1}^{n} b_i$. Building upon the work of Pan and Yang (2002), Pan and Yang (2008) proposed two fuzzy models. The first model incorporates the fuzziness of annual demand, while the second accounts for fuzziness in production and demand rates. Recently, Hoque (2007) developed an alternative model of the problem with equal or unequal sized batches transfer under controllable lead time for a JIT system. He then developed a heuristic solution algorithm of the model and showed cost reduction in comparison with Pan & Yang (2002) by solving the same numerical example solved by them. Srinivas & Rao (2007) developed a controllable-lead-time inventory model where the lead time is assumed to be dependent because at the time of contract with a vendor (manufacturer), the buyer (retailer) may intend to reduce the lead time, for which he will pay an additional cost to accomplish an increased production rate.
Ben-Daya & Hariga (2004) considered the single vendor single buyer integrated production inventory problem where demand is stochastic and the lead time is varying linearly with the

lot size; i.e., $L(Q) = \kappa Q + \zeta$. The integrated vendor buyer expected total cost per unit time is given by

$$ETC_{sc}(Q, r, \lambda) = \frac{D}{Q}\left(F + \frac{A_v + A_b}{\lambda}\right) + \pi_b \zeta(r, L(Q))\frac{D}{Q}$$
$$+ \frac{Q}{2}\{h_b + h_v[\lambda(1 - D\kappa) - 1 + 2D\kappa]\} + h_b SS_b$$

where $\kappa = 1/P$, ζ denotes a fixed delay due to transportation, production etc, F transportation cost for the buyer incurred with each shipment of size Q, π_b and SS_b are respectively the stock-out cost and safety stock at the buyer's end, r the reordering level, and the remaining parameters are as defined earlier in this chapter.
The authors assumed that demand during lead time is normally distributed with mean $DL(Q)$ and standard deviation $\sigma\sqrt{L(Q)}$, where

$$SS_b = k\sigma\sqrt{\kappa Q + \zeta}$$

$$\zeta(r, L(Q)) = \int_s^{\infty} (x - s) f\left(x, DL(Q), \sigma\sqrt{L(Q)}\right) dx$$

$$k = \left(r - DL(Q)\right) / \sigma\sqrt{L(Q)}$$

Wee et al. (2006) proposed a production-inventory model for an on-going deterioration item with partial backordering and imperfect quality, with shortages due to imperfect items are completely backordered. This is because not all customers are willing to wait for a new replenishment of stock. Customers encountering shortages will respond differently according to the type of commodities and market environment. The expected value of the joint total cost was given as

$$ETC_{sc} = \left[\frac{R}{\lambda T} - (DE[\rho] + D) - \left(\frac{E[p]\theta D^2}{x} + \frac{\theta D}{2} E\left[(1-\rho)^2\right]\right) T - \frac{E[\rho]\theta^2 D^3}{2x^2} T^2\right]$$

$$\times\left(\frac{h_v}{\theta} + d_v\right) + \frac{A_v}{\lambda T} + \frac{A_d}{T} + \frac{A_b}{T} + \left(c_b + c_x + d_b + \frac{h_b}{\theta}\right) \times$$

$$\left[DE[p] + D + \left(\frac{\theta D^2 E[\rho]}{x} + \frac{\theta DE\left[(1-\rho)^2\right]}{2}\right) T + \frac{\theta^2 D^3 E[\rho]}{2x^2} T^2\right]$$

$$-\left(d_b + \frac{h_b}{\theta}\right)(DE[\rho] + D) + \frac{\pi_b DT}{2} E\left[\rho^2\right]$$

Where R is the total production quantity, T is the buyer's cycle time, D is the demand rate, θ is the deterioration rate, x is the screening rate, ρ is the defective percentage which has a uniform distribution over $[\rho_0, \rho_1]$, A_d is the delivery cost, c_b the unit purchase cost per unit for the buyer, d_v is the deterioration cost per unit for the vendor, d_b is the deterioration cost per unit for the buyer, c_x is the screening cost per unit for the buyer and π_b is backordering cost per unit for the buyer.

Ritvirool & Ferrell (2007) modelled a single-vendor, single-buyer purchasing system in which the buyer uses a (Q, r) inventory policy and the vendor determines the production lot size on a make-to-order basis. They developed a cost based model that is used to determine the optimal order quantity and reorder point as well as the safety stock levels for both the vendor and buyer. The cost of quality is included by assuming that the vendor's inventory contains defective items. The total annual cost, TC_{SC} (Q, r), the total expected cost per cycle is given as

$$TC_{sc}(Q,r) = h_v\left(r - \frac{QD}{2P} - SS_b\right) + h_b\left(\frac{Q}{2} + SS_b\right) + (A_v + A_b)\frac{D}{Q}$$

$$+ D(c_p + c_I) + (c_p + c_I + d - v)\frac{D\delta\mu Q}{2P} + \pi_b n(r)\frac{D}{Q}$$

Where π_b is the buyer's shortage cost, $\pi_b\, n(r)$ is cost associated with back ordering, $1/\mu$ is the mean of the time τ when the production process shifts from in-control to out-of-control, c_p is the unit production cost, c_I is the unit inspection cost, an out-of-control process will result in $\delta\times$ 100% of the units being non-conforming and requiring replacement, N is the number of defective per cycle where $N = (t-\tau)\delta$ if $\tau < t$ and zero otherwise, $(d-v)E(N)$ is the cost of defective items where $E(N) = \delta\mu Q^2/2P$, and SS_b is the buyer's safety stock.

4. Three-level supply chain models

Gurnani (2001) considered the case where the supplier structures the quantity discount such that the buyers are encouraged to coordinate the timing of their orders (note that only the order timing is coordinated and that the order sizes could still be different). For the case of identical buyers, Gurnani (2001) showed that order coordination always leads to a reduction in the total system costs. However, for the general case of heterogeneous buyers, forcing order coordination on the buyers could result in an increase in the system costs. Later, Gurnani (2001) considered the case when the buyers place a combined (single) order with the supplier (referred to as "order consolidation"). For this case, the various buyers could be outlets at different geographical locations. In order to coordinate purchasing to take advantage of the quantity discount, a consolidated (bigger-sized) order is placed with the supplier. Upon receipt of the order at a centralized, it was assumed warehouse (say), the shipments are allocated to the outlets at the various locations. Finally, Gurnani (2001) considered the case of a `multi-tier ordering hierarchy where only one of the buyers (could be a major wholesaler) places an order from the supplier directly. The remaining buyers, in turn, place orders only from the major buyer. In such an ordering hierarchy, the supplier benefits since he deals with only one buyer and transactions-related costs are therefore lower.

Munson and Rosenblatt (2001) investigated a supply chain that consists of a supplier, a vendor (manufacturer), and a buyer (retailer). The buyer determines the order quantity using the economic order quantity (EOQ) model. The vendor offers quantity discounts which it obtains from its supplier and offers to the retailer to generate cost savings for itself. The vendor's lot size is an integer multiplier of the buyer's order quantity, and that of the supplier is an integer multiplier of that of the vendor.

Khouja (2003b) extended the work of Munson & Rosenblatt (2001) where he formulated and solve a three-stage, multi-customer, non-serial, supply chain inventory model, with multiple firms at each stage and a firm can supply two or more customers. He dealt with three coordination mechanisms, which are: (1) Equal cycle time, (2) Integer-multiplier at each stage, and and (3) Integer powers of two multipliers at each firm. Khouja (2003b) developed a supply chain cost for each case.

Lee (2005) considered a vendor (manufacturer), a buyer inventory control problem where the manufacturer orders raw materials from the supplier, then, through its production processes, converts the raw materials to finished products, and finally delivers the finished goods to the buyer. Six costs incurred in this supply chain, which are raw material ordering cost and holding cost, manufacturer's production setup cost and its finished goods holding cost, and buyer's inventory ordering cost and holding cost. Lee's objective was to develop an economic lot size model to minimize the integrated supply chain costs, while simultaneously taking the six costs above into accounts.

Lee and Moon (2006) developed inventory models for the three level supply chain; i.e., a supplier, a vendor (warehouse), and a buyer (retailer). The focus of their problem was determining the optimal integer multiple $\lambda_{.}$ of time interval, time interval between successive setups and orders in the coordinated inventory model. Lei et al. (2006) studied the channel coordination policies for a supply chain process involving a vendor (supplier), a buyer and a third party transportation partner. The transporter is assumed to have an operation cost structure similar to the one under a distribution service contract of the business case that motivated our study. That is, the transporter pays for a fixed (e.g., the packaging cost) and variable transportation cost for every order that the buyer places. They also assumed that the supplier controls the selling price to the buyer, pays for the shipping cost (i.e., the free-onboard contract with buyer), where the transporter charges supplier a shipping rate, be responsible for transporting the product from the supplier to the buyer, and bears his/her own operation cost, $a + bQ$, per order/ shipment, where parameter a stands for the fixed cost per shipment (e.g., value-added services per order processed, insurance per trip, and truck driver's cost, etc) and parameter b stands for the unit shipping variable cost (e.g., mileage cost and truck usage, etc). The market demand, $D(p)$, is assumed to be a commonly used decreasing convex function of buyer's selling price, p. The joint profit function was written as

$$\Pi_{sc} = (c_b - c_t - c_v)D(p) - \frac{A_v D(p)}{Q} - h_v \frac{Q}{2} + (c_t - b)D(p) - a\frac{D(p)}{Q}$$

$$+ (p - c_b)D(p) - \frac{A_b D(p)}{Q} - h_b \frac{Q}{2}$$

Defining c_t as the average shipping rate charged by the transporter (as the transporter's decision variable), and $c_t > b + a/Q$, where transporter's operation cost per order is assumed to be $a + bQ$. The other parameters are c_b (c_v) the buyer's (vendor's) unit purchasing price ($c_v < c_b < p$) from the vendor (as the supplier's decision variable), A_b (A_v) the buyer's (vendor's) fixed cost per order (setup), and h_b (h_v) the buyer's (vendor's) unit holding cost per year. The market selling price that maximizes this channel joint yearly profit is p^*.

Jaber et al. (2006b) proposed a three-level (supplier-manufacturer-retailer) supply chain model with a profit sharing mechanism to maximize the supply chain profit. In the model, all-unit price discounts scheme is used to coordinate the order quantities among the supply chain levels and the demand at the retailer's end is assumed to be price dependent. To enhance co-ordination in the supply chain, two profit sharing scenarios are investigated. The semi-liberal scenario is based on increasing the quantity discount in order to generate more demands with which the most powerful player in the chain will get the highest fraction of additional profits. However, a strict mechanism is suggested to rectify the first scenario by dividing coordination profits based on equal return on investments. The supply chain profit function is the sum of players profit functions of the supplier, the vendor (manufacturer), and the buyer. The mathematical programming problem could then be written as

Maximize $Z = \Pi_b(Q, d_b) + \Pi_v(Q, d_b, d_v, \lambda_v) + \Pi_s(Q, d_b, d_v, \lambda_v, \lambda_s)$

Subject to:

$$\lambda_s, \lambda_v \geq 1$$

$$d_s, d_v, d_b \geq 0$$

$$d_s \leq p_s - c_s$$

$$d_v \leq p_v - (p_s - d_s)$$

$$d_b \leq p_b - (p_v - d_v)$$

$$Q > 0$$

Where the unit profit functions of the buyer, vendor and supplier respectively are

$$\Pi_b(Q, d_b) = (p_b - d_b) f(d_b) - \frac{A_b f(d_b)}{Q} - c_b f(d_b) - h_b \frac{Q}{2}$$

$$\Pi_v(Q, d_b, d_v, \lambda_v) = (p_v - c_v - d_v) f(d_b) - \frac{A_v f(d_b)}{\lambda_v Q} - h_v(\lambda_v - 1)\frac{Q}{2}$$

$$\Pi_s(Q, d_b, d_v, d_s, \lambda_v, \lambda_s) = (p_s - c_s - d_s) f(d_b) - \frac{A_s f(d_b)}{Q \lambda_v \lambda_s}$$

$$-h_s \frac{Q}{2} \lambda_v (\lambda_s - 1)$$

And i = s, v, b (supplier, vendor, buyer), c_i is the procurement cost per unit for player i, $\tilde{p}_i$ is the non-discounted selling price for player i, p_i is the selling price for player i, d_i is the discount in price offered by player i to j where $i \neq j$, h_i is the holding cost for player i, $f(d_b)$ is the annual demand rate measured from the end side of the chain, assumed to be a linear function of the discount rate, $f(d_b) = D_0 + D_1 d_r$, where $d_b = 0$ means that the retailer is offering no price discounts to customers, and its demand rate shall remain at initial value D_0, i.e. $f(0) = D_0$, $A_i =$ set-up/order cost per cycle for player i, Q is the order quantity for player i, and λ_i is an integer multiplier to adjust the order quantity of player i to that of j where $i \neq j$. Jaber et al. (2006b) assumed a single product case, no shortages to occur, zero lead-time, perfect quality items, and infinite planning horizon. We also assume that demand is price dependent and the cost parameters do not vary over time.

Banerjee et al. (2007) develop an integrated inventory model for coordinating the procurement of input materials, albeit in somewhat of a limited way, with the production schedule, which, in turn, is linked to the product distribution and delivery plan. They adopted the concept of integer lot size factors as potentially effective mechanisms for establishing linkages among inventories at various echelons of the supply chain for achieving coordination. The aggregate total supply chain cost per time unit for the manufacturing (vendor), retail (buyer) and the pre-production (suppler) supply stages of the entire chain was given as

$$TC_{sc}(Q, \lambda_v, \lambda_s) = \frac{D}{Q}\left[A_b + \frac{1}{\lambda_v}\left(A_v + A_s\lambda_s\right)\right] + \frac{Q}{2}\left\{h_b + h_v\left[(2-\lambda_v)\frac{D}{P} + \lambda_v - 1\right] + \frac{\lambda_v D h_s}{P\lambda_s}\right\}$$

Where A_i, h_i (i = s, v, b), and λ_i (i = s, v) are as defined above (Jaber et al. 2006b), $D = \sum_{i=1}^{n} D_i$ is the aggregated demand rate at the ends of the buyers, P is the production rate (P > D), and $Q = \sum_{i=1}^{n} q_i$ is the total units delivered to buyers. Each input materials bundle is delivered to the production facility in λ_s (a positive integer) equally split lots. It is clear that, consistent with the JIT approach, $\lambda_v Q/\lambda_s$ units of the composite materials input are delivered L times at regular intervals during each production cycle. The optimal values of Q, λ_v, and λ_s were given as

$$Q = \sqrt{\frac{2D\left[A_b + (1/\lambda_v)(A_v + A_s\lambda_s)\right]}{h_b + h_v\{[(2-\lambda_v)D/P] + \lambda_v - 1\} + \lambda_v D h_s / P\lambda_s}}$$

$$\lambda_v = \frac{1}{Q}\sqrt{\frac{2D(A_v + A_s\lambda_s)}{h_v(1 - D/P) + h_s D / P\lambda_s}}$$

$$\lambda_s = \lambda_v Q\sqrt{\frac{h_s}{2PA_s}}$$

5. Four-level or more supply chain models

Pourakbar et al. (2007) considered an integrated four-stage supply chain system, incorporating one supplier, multiple producers, multiple distributors multiple retailers. The aim of this model is to determine order quantity of each stage (from its upstream) and shortage level of each stage (for its downstream) such that the total cost of the supply chain to be minimized. Their model is an extension of the work of Lee (2005) from a linear three stages supply network including producer, distributor and retailer to a four stages supply network by adding one supplier. The complexity of the problem necessitated the development of heuristic solution procedures based on Genetic Algorithm to solve this problem. The model was investigated for the three coordination mechanisms described in Khouja (2003b), which are: (1) Equal cycle time, (2) cycle time at each stage of the chain is an integer multiplier of the cycle time of the adjacent downstream stage, and (3) the cycle time of each firm was an integer powers of two multiplies of a basic cycle time. Pourakbar et al. (2007) assumed a single product when buyers' shortages are backlogged.
Cárdenas-Barrón (2007) extended the work of Khouja's (2003b) three-stage supply chain by presenting an n-stage-multi-customer supply chain inventory model. He solve the cost function applying the algebraically (Grubbström & Erdem, 1999). Cárdenas-Barrón (2007) selects the equal cycle time coordination mechanism for two reasons: the first one is that this Mechanism is the most simple and the second one is because our main purpose is to develop a useful supply chain model that can be taught without the use of calculus. He limited his mathematics and numerical examples to a 4-level supply chain (supplier-, where he assumed a single product. The total supply chain cost was of the form

$$TC_{sc} = T\left\{\frac{VDh_n + \sum_{i=1}^{n-1}\left[\left(h_{i-1}+h_i\right)\sum_j D_{i,j}^2 Y\right]}{2V}\right\} + \frac{1}{T}\sum_{i.j} A_{i,j} \quad \text{for all } i, j$$

Where V is the product of all production rates for all companies in the supply chain, and Y is the product of all production rates for all companies in the supply chain, except for company j in stage i as Khouja (2003b) stated, $A_{i,j}$ is the setup or ordering cost for a company j at stage i, $D = \sum_{j=1}^{J_1} D_{1,j} = \sum_{j=1}^{J_2} D_{2,j} = \cdots = \sum_{j=1}^{J_{n-1}} D_{n-1,j} = \sum_{j=1}^{J_n} D_{n,j}$, D is the total demand at each stage, being the same demand across stages, J_i is the total companies at stage i, h_{i-1} is the holding cost of raw material for a company j at stage i, and h_i is the holding cost of finished products for a company j at stage i. The above cost function was minimized subject to $T > 0$.

6. Conclusion

This chapter presented a review of quantitative models for centralised supply chain coordination. Although we do not claim that this review has exhausted all related articles, we have reviewed most significant models available in the literature between 1990 to mid 2007. The chapter classifies the existing literature on the centralised supply chain coordination into three groups: a) two-level supply chain, b) three-level supply chain, and c) four or more levels. With majority of publications being in the first group, it is noticeable that the general case of *n*-level (centralised) supply chain coordination has not been adequately investigated. Also, it can be seen that the literature has focused either on single item/multi level supply chain or on multi-item/two-level supply chain. There has not been any significant study on multi-item/multi-level supply chain coordination and this could well be another direction for future research. It was also noticed that the majority of the centralised supply chain coordination literature is based on deterministic models. In reality, stochastic supply chain is more likely to be the case as demand, lead time, quality, and price (among other things) are stochastic in nature. Another observation that emerged through this literature review is that, similar to classical inventory optimization, the existing literature takes a cost optimization approach. The problem with this approach is that such models assume most of the cost parameters (such as holding costs and ordering costs) are readily available. In reality, such parameters may not be easily determined; therefore, the validity of such cost functions is questionable. Instead, other quantitative and qualitative performance measures such as the coordination impact on the quality of the firm's relationship with its suppliers, or the effect of such coordination on streamlining the business process in each player's organization should be considered.

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18

Moving Segmentation Up the Supply-Chain: Supply Chain Segmentation and Artificial Neural Networks

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1. Introduction

Market segmentation, a central concept of a market orientation has focused primarily on managing heterogeneities on the demand side of a market. However, in order to meet consumer demands that are becoming more complex (such as the mass customization of products), firms may find it beneficial to optimally manage and coordinate heterogeneities, not only on the demand-side of a market but also on the supply-side. In other words, to manage the supply chain more effectively, firms may need to segment the supply-side of the marketplace. Thus, the entire supply chain could deal with heterogeneities on both the demand and supply-side more effectively.

To do so, the concept of "supply-side segmentation" is presented, which is defined as "a state of supply chain heterogeneity, where the total supply pool can be disaggregated into segments that potentially can satisfy distinct demand functions in the market place (Erevelles et al., 2001)."By using segmentation at different levels of the supply-chain, firms can not only find an appropriate segment on demand side of a market that their product or service can satisfy relatively well, but also efficiently find a disaggregated supply-side segment that potentially can satisfy the needs of the previously identified demand-side segment or another supply-side segment in the supply chain.

Further, for the purpose of simultaneously aligning these supply-side and demand-side segments at all levels of supply chain, the concept of "transvectional segment" is suggested. This "transvectional" view of the supply chain goes beyond the "transactional" view, an implicit characteristic of market segmentation in most of the past literature. In this viewpoint, a firm is not just partnering with its immediate supplier in producing a product or service for the next immediate downstream customer, as viewed in a transactional approach to the supply chain. Rather, the firm is partnering simultaneously with all upstream suppliers, as well as with all downstream users to conglomerate and optimize all resources in the supply chain.

In order to analyze this complex heterogeneity of both the supply-side and demand-side of the market, the use of the Artificial Neural Network (ANN) is proposed. Although ANN has been applied in other disciplines, partly as a method of classification, its application in segmenting markets has been limited (Boone & Roehm, 2002). Considering the advantages of ANN to other types of classification methods, this is a bit surprising. ANN is an appropriate method especially in the classification of complex relationships (e.g., Hair et al., 1998), where many variables (i.e., segmentation criteria) are used for classification (Dreyfus, 2005, p.25) and where nonlinear relationships exist between the segmentation criteria and the behavior of individuals of interest (e.g., Clancy & Roberts, 1983). In segmenting each levels of the supply chain, and connecting these segments together as a "transvection," the perceived characteristics of the supplier or the product at all the levels of the supply chain have to be taken into account. Thus, the ANN would be an appropriate method of analysis to uncover the complex relationships among supply-side and demand-side segments simultaneously.

The concepts presented in this paper assume interdependencies among channel members that potentially could result in long-term benefits such as flexibility, reduced response time and cost reduction for all channel members. In sum, the concepts of supply-side segmentation and transvectional alignment provide a comprehensive and dynamic method for effectively managing the supply chain.

2. Literature review

Relationship between firms within a supply chain has been a topic of interest in both academic and trade literature. Ross and Robertson (2007) discuss the concept of "compound relationships," that are multiple, though distinct relationships (e.g., customer, competitor, partner, and supplier) between the same two organizations (i.e., a firm can have relationships as a customer and as a supplier with the same organization). Their paper is part of a growing body of research that focuses on how to improve the performance of relationships among multiple firms in a supply chain, rather than only relationships relating to a single "focal" firm in the supply chain. The focus of this paper also is on the relationships among firms in a supply chain, taken as a whole. But, while Ross and Robertson (2007) considered the multiple relationships of two firms as the unit of analysis, our paper focuses on the relationships of the entire "transvection," i.e., multiple firms at different levels of the supply chain, as well as customers.

As customers are increasingly becoming more involved in the creation of products or services (e.g., co-creation), customers become a source of competence in a market (Prahalad & Ramaswamy, 2000; Vargo & Lusch, 2004). This makes it especially important to construct a supply chain that meets the needs of customers more effectively and efficiently. However, as Prahalad and Ramaswamy (2000) note, scholars have focused more on how companies can achieve a competitive advantage by "competing as a family" and less on how companies can also include customers in their network of value creation.

To resolve this issue, some scholars have proposed the concept of demand chain management. Demand chain management can be defined as "a set of practices aimed at managing and coordinating the whole demand chain, starting from the end customer and working backward to raw material supplier (Selen & Soliman, 2002; c.f., Juttner et al., 2007)." Juttner et al. (2007) argue that demand chain management starts with understanding the heterogeneous needs of the customers, and how to satisfy these demands instead of starting with the supplier or manufacturer. Thus, the flow of designing the demand chain is from downstream customers to upstream suppliers. In order to build an effective and efficient demand chain, a firm needs to efficiently align the heterogeneity of the "supply side" with the heterogeneity of the "demand side." Consistent with this notion, Reekie and Savitt (1982) state that a firm's position in a market depends on how a firm can effectively match supply and demand. Regarding the heterogeneity of demand side and the supply side, Alderson (1965, p. 29) notes that "each market segment of demand can be satisfied by one unique segment of supply" when the market is completely heterogeneous. Our concept of "supply side segmentation" and "transvectional segmentation" provide a systematic solution to align the supply-side and demand-side heterogeneity more effectively.

3. Theoretical framework

Supply-side segmentation

Using the concept of market segmentation, where the heterogeneity of preferences for products/services in demand side of a market are assumed, firms react to these heterogeneous needs of customers by (1) adding new offerings, (2) modifying current offerings, or (3) repositioning the current offerings when it is beneficial to do so (Green and Krieger, 1991). The most of the discussion about market segmentation is about how a single firm can deal with many types of preferences of customers. However, heterogeneity exists not only in demand side of a market but also in the supply side of a market. For instance, some suppliers are good at offering computer parts at a relatively low cost. Other suppliers may be good at producing specialized computer parts for ultra portable laptop computers. In 1960's, Alderson (1965, p. 29) explicitly mentioned the heterogeneity of supply side of a market by stating that the major function of a market is to match "differentiated segments of demand with the corresponding segments of supply". Alderson asserts that when heterogeneity of supply side and the heterogeneity of demand side are matched perfectly, no products or services are left unsold.

Dickson and Ginter (1987) illustrated market demand in the following equation.

From a manufacturer's perspective, the buyer's demand function is:

$$Q = f\,(p_c, x_1, \ldots x_n),$$

where:

- "Q" represents demand for a particular product offered by a manufacturer
- "p_c" represents the price offered by the manufacturer to a buyer, and
- "$x_{1\text{-}n}$" represents buyer perceived product characteristics.

This demand function can be applied to all the levels of supply chain. In other words, the demand function for offerings of a certain supplier by its immediate customers in the supply chain can be expressed as follows;

$$Q = F\,(p_c, y_1, \ldots, y_n) \text{ --- } (2)$$

- p_c: represents the price offered by a supplier to its immediate customer
- y_1, y_2, y_3, --- y_n: Perceived supplier/product characteristic

This function can be generalized for each level of supply chain

$$Q_{k-1} = F_{k-1} (p_c , y_{1k},...,y_{nk}) \text{ --- } (3)$$

- p_c : represents the price offered by a supplier to its immediate customer
- k: levels of supply chain
- y_{1k}, y_{2k}, y_{3k}, --- y_{nk}: Perceived supplier/product characteristic for a supplier in kth level of supply chain

Based on the heterogeneity of demand at k-1 level of the supply chain, the supplier or offerings at kth level of the supply chain can be divided into certain number of segments. That heterogeneity of demand is based on the perceived characteristic of a product or a supplier (please see figure 1 for the illustration using the example for personal computer industry).

Transvectional Segmentation Strategy

Once the suppliers at each level of the supply chain is segmented into a certain numbers segments, how can a firm or a set of firms in the supply chain can make use of this supply-side segments to adapt better in today's turbulent environment (e.g., modify an offering to the changing needs of customers)? In order to answer the question, the concept of transvectional segmentation is presented in this section. Alderson and Martin (1965) introduced the concept of transvection, in contrast to transaction. They assert, "the transactions as such are limited only to the successive negotiations of exchange agreements." So, in figure 1, transactions are exchanges between supplier at level k and its immediate customer (supplier at level k-1). These exchanges are expressed as a form of demand function Qk-1. In contrast, Alderson and Martin (1965) defined a transvection as "a unit of action of the marketing system resulting in placing a final product in the hands of the consumer but reaching all the way back to the raw materials entering into the product." They also mention, "a transvection is in a sense the outcome of a series of transactions." Thus, in our framework, transvection can be defined as a series of transactions (expressed as demand function Qk) between a supplier and its immediate customer, which result in offering a final product to a consumer. Then, transvectional segment can be defined as a cross-section of the marketplace, consisting of suppliers, manufacturers and customers, optimally aligned to fulfill the demand function of a supplier at each level of supply chain. The demand function of transvection consists of a series of demand functions in each level of a supply chain. This means that the demand function of a transvection is affected by the change of demand function of end customers (e.g., change of preference of customers). (For further elaboration on supply-side segmentation and transvectional segmentation strategy, please see Erevelles et al. 2001 or Erevelles & Stevenson, 2006.)

4. Artificial neural networks in market segmentation

Although the concept of Artificial Neural Networks (ANN) has been applied in many disciplines, its application in marketing has been limited. Boone and Roehm (2002) note that "only a handful of marketing researchers have examined ANNs as a market segmentation tool." It may be beneficial to apply ANN to our supply side segmentation approach. As discussed, we believe that ANN is especially appropriate to assess the supply-side and demand-side heterogeneities of the entire supply chain, which tend to be complex and nonlinear.

The major components of an artificial neural network are input nodes (where each node represents a single variable), output nodes (that process the input from the input nodes and compute the final output value that is used for classification) and hidden nodes (i.e., what is located between input nodes and output nodes) (Hair et al., 1998). As Hair et al. (1998) suggest, the advantage of the neural network model is its capability of dealing with complex problems and that of improvement by learning. More specifically, they argue that the hidden layer that serves like a cushion between input and output nodes gives the model a capability of processing complex problems including nonlinear relationships better than other types of classification methods. Also, they argue that the learning capability allows the model to improve the model fit by itself; the error (i.e., the difference between the actual and estimated classification) is sent back to the model and the weight given in each path is re-calculated to reduce the error. This learning capability allows researchers to apply the model without priori assumptions in terms of the relationship in the model, since the model itself examines data and "maps an approximation of the relationship" (Fish et al., 1995).

Because of these advantages, ANN applications have been used in traditional market segmentation, albeit in a limited manner (e.g., Fish et al. 1995; Natter, 1999; Dasgupta et al., 1994; Boone & Roehm, 2002; Hruschka & Natter, 1999; Kuo et al., 2002). For instance, Fish et al. (1995) applied the artificial neural network (ANN) for market segmentation in a B2B context and compared its classification capabilities with other methods (e.g., discriminant analysis and logistic regression). They note the superior classification ability of ANN when compared with discriminant analysis and logistic regression. Natter (1999) argues that ANN performs better than other types of stepwise approach in the formation of market segments that shows both good homogeneity and distinct behavior. Kuo et al. (2002) applied ANN to determine the number of clusters and then, used K-means method to form the clusters. Their two-stage model takes advantage of ANN's learning capability of figuring out the optimal number of clusters by itself. This advantage is crucial in market segmentation since, "if the appropriate number of segments are over specified, marketers may over-segment the market and treat audience segments separately that could effectively be treated inclusively" (Boone & Roehm, 2002).

Application of Artificial Neural Networks in Supply-side Segmentation

"Transvections" are formed by connecting supplier segments across multiple levels of the supply chain (e.g., raw material supplier, sub-component supplier, manufacturer etc.). Thus, transvectional segments tend to become more complex than traditional types of demand-side market segments that include only one level of the supply chain. Since the input variables include the perceived supplier or product characteristics at *all* levels of the supply chain, the analysis needs to simultaneously consider a large number of input variables. As Dreyfus (2005, p. 25) argues, the neural network is an appropriate method of analysis when the number of variables is relatively large. Also, the demand function in a transvection reflects the demand function of all successive downstream members of the supply chain. As table 1 indicates, manufacturers often deal with a substantial number of suppliers. As a method of investigating this complex phenomenon, ANN may have an advantage over other types of methods of analysis.

In addition, as Fish et al. (1995) suggests, ANN does not require a priori assumptions in modelling the relationships. The model basically let all the variables connect to all the nodes in hidden layers. The model computes the magnitude of the relationships (Fish et al. 1995) as a form of weight. This characteristic of the model allows us to illustrate transvectional segmentation in a realistic way. Since perceived characteristics of a supplier at level k in the supply chain are more likely to be associated with multiple transvectional segments in the hidden layer, the capability of the model for computing the magnitude of the relationships from each node of input level to each node at the hidden layer is crucial to our analysis of transvectional segmentation.

Traditional Market Segmentation vs. Transvectional Market Segmentation

Traditional market segmentation takes a demand-side approach, considering only downstream demand. Thus, from a manufacturer perspective, the buyer's demand function only includes the buyer's perceived product characteristics in the context of simple buyer and seller perspective.

Thus, from a manufacturer's perspective, the buyer's demand function is (please see Dickson and Ginter, 1987):

$$Q = f\,(p_c, x_1, \ldots x_n),$$

where:

- "Q" represents demand for a particular product offered by a manufacturer
- "p_c" represents the price offered by the manufacturer to a buyer, and
- "$x_{1\text{-}n}$" represents buyer perceived product characteristics.

However, we suggest that market segmentation can be extended to manage *upstream* demand more effectively and efficiently. In other words, by segmenting multiple levels of the supply chain both *upstream* and *downstream*, the manufacturer, for instance, can choose appropriate suppliers up-the-supply chain in an efficient manner that effectively meet downstream customers' demands. Eventually, the manufacturer and the other members of the supply chain can form trans-intermediary alignments called "transvectional segments" (please see Erevelles et al. (2001) for elaboration). Therefore, the transvectional demand function takes a supplier, manufacturer, customer and other supply chain members into consideration. The artificial neural network model can be used to segment existing relationships across the supply chain to form a transvectional segment (each node in the hidden layer) based on the perceived supplier or product characteristics of customers, manufacturers, and multiple levels of suppliers (input nodes). In a practical sense, a researcher may identify existing relationships in the supply chain and assess the perceived characteristics of each channel member in that relationship to identify the transvectional segment.

The output from each node in a transvectional segment can be calculated as follows (see Fish et al, 1995):

$$Z = \Phi \sum_{k=1}^{l} \sum_{n=1}^{j} (w_{nk} \cdot y_{nk} - \theta)$$

where

- Z: output value from input node into the hidden node
- $y_{nk:}$ perceived supplier/product characteristics

- w_{nk}: connection weights
- n: the number of supplier/product characteristics in each level of supply chain
- k: the number of levels of supply chain
- θ: activation threshold
- Φ: differentiable function

Once this output from the hidden node is sent to the output node, the output node computes the final value and compares the value with the actual value (if any). The ANN calculates the error between the estimated value and the actual value. Then, w_{nk} (weight) is adjusted to minimize the error. This weight that is an indicator of the magnitude of the relationship between the input node and the hidden node will allow us to figure out which characteristic in which level of the supply chain is associated better with a certain transvectional segment (Please see figure 2 for illustration).

5. Conclusion

This paper explained the concept of supply-side segmentation and transvectional alignment, and applies these concepts in the artificial neural network (ANN). To the best of our knowledge, no research has applied ANN in explaining the heterogeneity of both the supply-side and demand-side of a market in forming relational entity that consists of firms at all levels of the supply chain and the demand chain. The ANN offers a way of operationalizing the concept of supply-side segmentation. In today's business environment, where competition occurs more among the networks that consist of sets of firms rather than simply among firms, researchers and practitioners need to understand the heterogeneity of the supply side of a market at all levels in the supply chain. Also, as firms co-create with customers to take advantage of their feedback to improve their offerings continuously (Vargo & Lusch, 2004), more firms are encouraged to adapt to the changes of customer preference in a precise manner. Supply-side segmentation offers a framework for a firm to manage the heterogeneity of the supply-side and demand-side at all levels of the supply and demand side of a market in a systematic way.

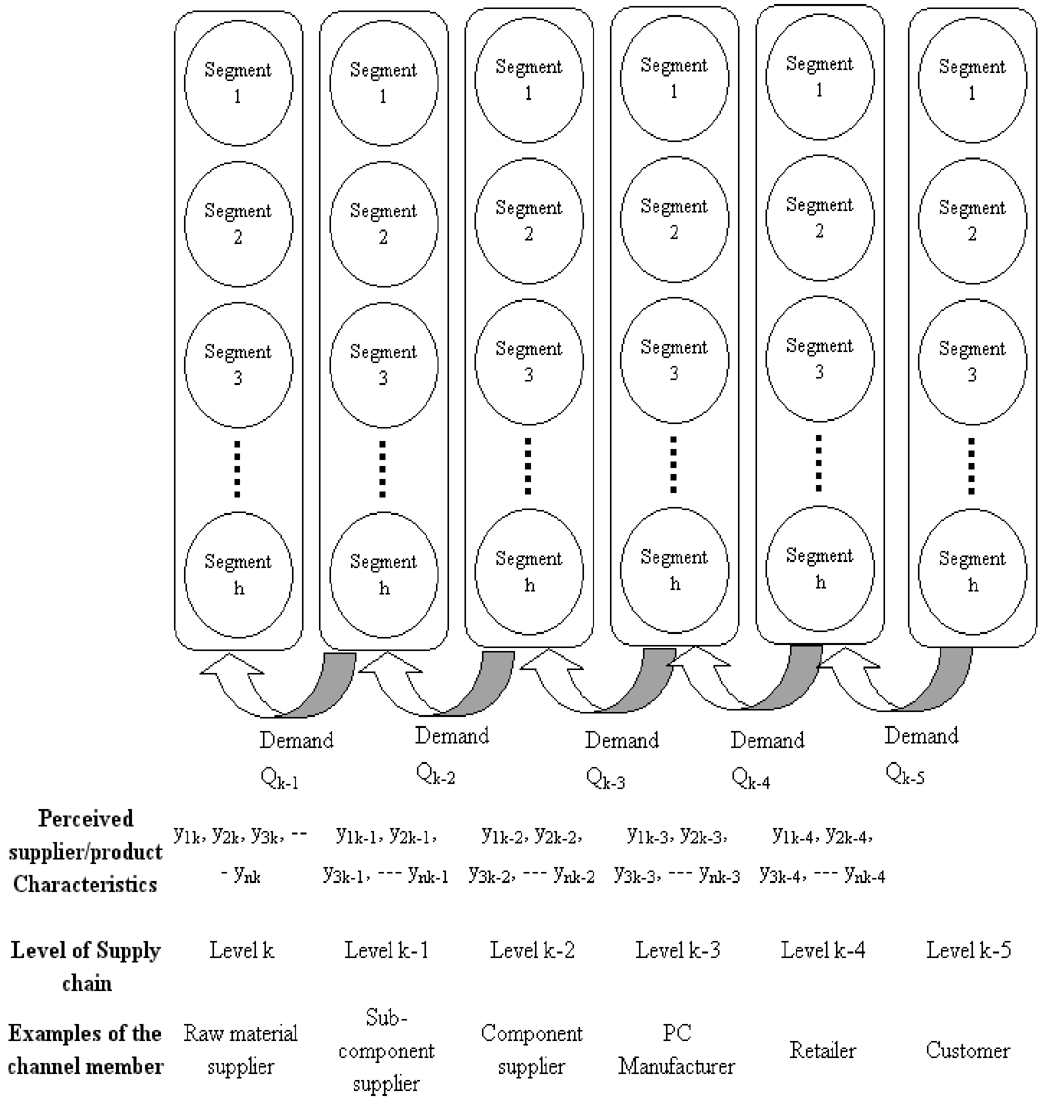

Figure 1. Illustration of Supply-side segmentation – supply chain for personal computer industry

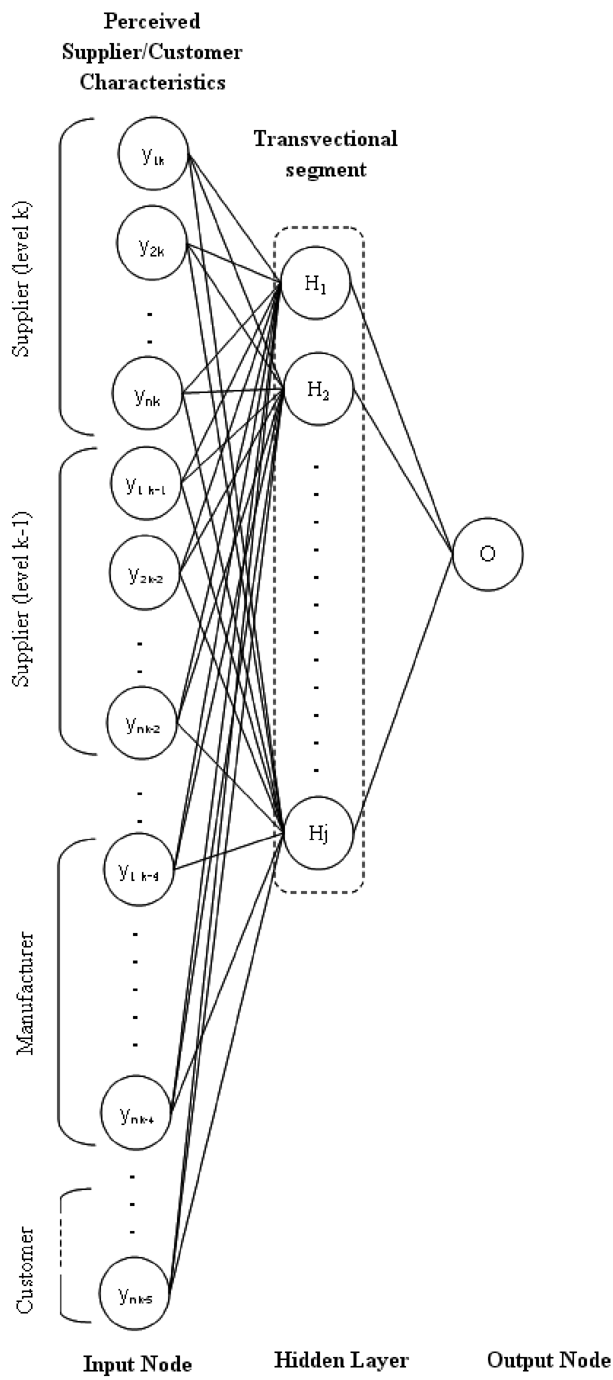

Figure 2: Illustration of Transvectional Segmentation with Artificial Neural Network

Company	*Number of direct suppliers*	*Comments*	*Source*
Boeing	20,406	Expects suppliers to produce larger assemblies rather than individual parts to reduce complexity of supply chain	Wilhelm (2001)
Ford	11,000	2,000 Production suppliers, 9,000 non-production goods and service providers	Ford Motor Company (2005)
General Electric	35,000	Utilize online market place where electronic auctioning, invoicing, and demand forecasting are available	Logistics Today (2003)
General Motors	10,000	General Motors reduced its suppliers to 10, 000 in 2000.	Entrepreneur.com (2003)
Hitachi	13, 000	Formed alliance with E2open to establish world's largest B2B e-commerce platforms	Spiegel (2002)
Wal-Mart	30,000	Expects suppliers to monitor the data daily and respond to problems immediately	Thomas (2002) D'Innocenzio (2003)

Table 1. Examples of Supply Chain Size

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19

A Dynamic Resource Allocation on Service Supply Chain

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1. Introduction

Recently, as internet business is growing rapidly, it has been bringing a lot of changes in many aspects of commercial business activities, and especially internet shopping malls, dealing with individual consumers, have continued radical changes and development. Thus, internet-based companies are required to implement variously different and new approaches in the ways of conducting their businesses. Therefore, it is becoming one of the most significant strategic elements for internet-based companies to correctly understand the purchase patterns of individual consumers and properly provide business environments that can give the maximum satisfactions to those individual consumers in service supply chain.

However, despite this radical change in the environment of internet shopping, it is true that most studies on internet-based businesses so far tend to just focus on such studies as the overall size of internet business, investigation on current market status, and practical study on consumer buying patterns from the perspective of consumers, lacking studies in such fields as the strategic management method from the perspective of companies and business investment decisions. Not to mention the lack of such studies as how the shopping mall management strategies, currently being used by the majority of internet-based companies, influence attracting customers to make purchase and customer satisfaction, and how customers' reactions from these strategies are affecting the management outcomes of business entities. Having these as the background in this study, the structure and the strategy of internet-based companies are analyzed based on dynamic speculations which emphasize an internally circulating feedback structure, as getting away from the currently existing linear speculations. Also, a speculative framework for decision makers to learn and understand the behavioral mechanism of the buying decision process is provided by building a system dynamics simulation model which can support long term decision making in the overall speculation instead of the direction of partial and short term oriented approaches. In doing so, the study intends to derive the most efficient investment decision support model for internet-based companies to operate their internet shopping malls in an overall way by understanding the correlation and interdependency among political variables, being needed for the operation of internet-based companies.

For this purpose, after going through the systematic classification and the analysis of existing literature and documentary records related to the internet shopping mall, in this research, four elements - internet advertisement, price reduction, web contents and web server - are derived as the primary factors influencing the buying decision before purchase. And the quality of delivery service and the service of customer support are selected as the variables influencing customer satisfaction and repeat purchases after initial purchase. By doing so, a general business model of internet shopping malls is developed. Additionally, the system dynamics model, which can support decision making for dynamic resource distribution of the overall internet shopping mall, is developed by combining the circulating interactions of cause and effect of individual feedback loop on each influencing variables and the feedback loop of the profit structure of internet shopping mall. In order to evaluate the validity of this dynamic resource distribution model, an internet bookstore, which is one of the most common types of internet shopping malls, is selected as a sample case.

	Statistical Approach	System Dynamics Approach
1. way of Inference	Previous empirical data	Logical causal relationships among variables
2. Analysis Subject	Static behavior	Dynamic behavior
3. Analysis Focus	Correlational Relationships	Feedback Relationships
4. Analysis Purpose	Numerical Accuracy	Structural Accuracy
5. Prediction	Short-term Prediction	Long-term Prediction
6. The Experiment of Various Policies	Difficult	Easy

Table 1. A comparison of existing research method and system dynamics method on the internet shopping

This study analyzes the Internet utilization pattern of customers by comprehensively investigating the previous studies on the behavior pattern of customer in terms of Internet business among the service supply chain using system dynamics. In other words, this study analyzes the behavioral changes of resource allocation of internet shopping malls in service supply chain. Also, under the assumption of an ever-growing and ever-developing industry of internet shopping, this study examines the aspect of dynamic changes of the closed feedback circulation structure in which created profits are invested in other resources of companies, making an increase in resources, subsequently resulting in the increase of productivity, customer satisfaction, and profit re-generation. Based on the analysis, this study develops a research framework that supports strategic decision-making for Internet business resource allocation. Based on the above analysis, this study provides meaningful suggestions on a set of advisable investment portfolios that can bring the most optimized profits to companies. Such research framework would be helpful for providing a typology of Internet business model that can be specialized by each industry.

2. Literature review on key elements for purchasing in the internet shopping mall.

2.1 Decision making steps for the purchasing in the internet shopping mall.

Individual consumers, under the environment of Internet, go through various steps of decision making to finally reach the step of making an actual purchase. This process itself varies depending on the kind of product, the consumer's individual character, and the purchasing status of the product. Generally speaking, consumers go through the steps of problem cognition, information search, alternative evaluation, buying decision, and evaluation after purchase. An Internet-oriented purchase also goes through same steps as the decision making model for a general purchase. However in the internet-oriented purchase, compared to the offline market, due to the uniqueness of the internet, the processes for information search and alternative evaluation can be carried out rapidly, and the potential problems caused by the lack of information and the lack of judgment objectivity can be minimized through providing various supports needed for purchase decision making.

In Finskud(2003)'s study, consumer's buying steps were divided into 6 different steps such as non-cognitive step, cognitive step, knowledge acquiring step, consideration step, purchasing step, and loyalty step. By using these 6 steps, 6 processes related to purchase such as recognition process, knowledge acquiring process, process for feeling attractive to, evaluation process, and purchasing process were established.

Also in the study by Cleland(2000), channels related to customer purchase are categorized by non-cognitive customers, cognitive customers, browsers, users, and loyal customers. And for each category, the degrees of influences from 8 different elements (Connectivity, Communication, Content, Convenience, Community, Customer care, Customization, Consent) are analyzed.

Another research, which analyzes the behavioral pattern of Internet shopping, is the web conversion efficiency model by Berthon et al. (1996). In this study, the web was regarded as advertising media, thus the flow of an Internet surfer's action was modeled as a 6 stepped process (surfer → aware surfer → hits → active visitors → purchases → repurchases). Furthermore, the concept of 5 step measurement ('aware efficiency', 'locatability / attractability efficiency', 'contact efficiency', 'conversion efficiency', and 'retention efficiency') was suggested.

Also, Kalakota & Whinston(1996) explained decision making steps for product purchase through the internet by classifying three different steps of 'pre-purchase interaction, purchase consummation, and post-purchase interaction.

2.2 The purchasing elements for internet shopping

In this study, as variables which make potential consumers aware of a product or brand and attract people to visit an internet shopping mall, elements related to marketing promotion such as internet advertisement, internet promotion, sales promotion activity, and the word of mouth activity are defined. Also, strategic variables related to actual purchase from an Internet shopping mall are categorized into three variables of price discount promotion, the quality improvement of web system, and the intensification of web contents. And strategic elements related to customer satisfaction after purchase are categorized into the quality of delivery service and the quality of customer support. Strategic variables such as price promotion, web system quality, and quality of web contents have meaningful effects on the level of customer satisfaction. The level of customer satisfaction is the collective concept of the website features of Internet shopping malls such as the web system and web contents. The quality of delivery service and customer support service, which are the evaluation elements for measuring customer satisfaction after purchase, are the variables related to service quality inducing re-purchase or market exit through satisfaction or dissatisfaction by customers. The previous studies on service quality elements related to Internet purchase are as follows.

Variables	Researcher
Internet Advertisement & Promotion	Berthon, P., Pitt, L.F., and Watson, R.T. (1996), Cleland. Robin S. (2000), Ducoffe, Robert H. (1996), Grover, R. (1992), Peterson, Robert A., Sridhar Balasubramanian and Bart J. Bronnenberg (1997),Smith, R. E. & Vogt, C. A. (1995).
Word of Mouse	Bone, P. F. (1995), Bristor, J. M. (1990), Chrysanthos Dellarocas (2003), Ellison, G. and Fudenberg, D. (1995), Gelb, B. and Johnson, M. (1995), Harrison-Walker, L. J. (2001), Richins, M. L. (1983), Richins, M. L. & Root-Shaffer, T. (1988), Singh. Jagdip (1990), Smith, R. E. & Vogt, C. A. (1995), Sundaram. D. S., Motra. K., & Webster. C. (1998).
Price Promotion	Bailey, J. P. (1998), Grewal, Dhruv and Howard Mannorstein (1994), Kalra, Ajay and Ronald C. Goodstein (1998), Krishnamurthi, Lakshman and S. P. Raj (1985), Roughgarden, J. (1998), Smith, Michael F. and Indrajit Sinha. (2000).
Quality of Web System	Bucklin, Randy and Catarina Sismeiro (2000), Donthu, Naveen (2001), Dorian S. and Schubert, P. (1998), Lin, J. C., and H. Lu (2001), Liu, C. and K. P. Arnett (2000), Sedehi, H, Boscolo, F and Vaccaro, N. (2000), Wan, H. A. (2000), Yoo, Boonghee & Naveen Donthu (200l).
Quality of Web Contents	Barnes, S. J., and Vidgen, R. (2001), Dholakia, Utpal M., and Lopo L. Rego (1998), Davis, F. (1989), Dorian S. and Schubert, P. (1998), Egger, Florian N. (2000), Ghose, Sanjoy and Wenyu Dou (1998), Huizingh, E. K. R. E. (2000), Moe, Wendy and Peter Fader (2001a), Urban, G., Fareena, S. and William Qualls (1999).
Quality of Delivery	Bienstock, Carol C., John T. Mentzer, and Monroe Murphy Bird (1997), Brynjolfsson, Erik and Michael D. Smith (2000), Erik R. Larsen, Ann van Ackere and Kim Warren (1997), J. T. Mentzer, J. F. Daniel, and J. L. Kent (1999), J. T. Mentzer, J. F. Daniel, and G. M. T. Hult (2001), Membrillo, Annabel, James Ritchie-Dunham, and Conrado García Madrid (1999), Oliva, R. and Sterman, J. D. (2001), Randall, L. and M. Senior (1992), Zeithaml, V.A., A. Parasumaran and L.L. Berry (1990).
Quality of Customer Support Service	Anton, J., Vivek, B. and Bill, H. (1999), Feinberg, R. A., I. Kim, B. Hokama, K. Ruyter, and C. Keen. (2001), Fung K. K. (2001), Garnett, O., A. Mandelbaum, and M. L. Reimann (2002), Grossman, T. A., D. A. Samuelson, S. L. Oh, and T. R. Rohleder (2001), Mandelbaum, A. and N. Shimkin (2000), Saltzman, R. and V. Mehrotra (2001).

Table 2. Literature review of major variables for online purchasing

3. Research model and methodology

3.1 Conceptual framework

As can be seen in figure 1, the conceptual framework is constructed based on previous literature. Potential customers go through each step of the Internet shopping market by recognizing the existence of online shopping malls with the use of the internet. As Internet users go through each step, they create profits for internet based companies by sometimes being just one-time buyers or by sometimes being loyal customers depending on the operation strategies of internet shopping malls. Depending on the investment ratio by strategic decision making, these profits are re-invested back into the operations of internet shopping mall, which is the process of company growth. In other words, the whole flow goes through the following process in circulation; Investment with efficient resource allocation → Promotion for the purchase/re-purchase of internet oriented customer → Profit generation → Re-investment in the operating resources of internet based companies. Thus, it is impossible to understand the process for explaining the growth of Internet based company in the perspective of a simply continuous linear process, and the process for growth can only be understood when intricate circulating interactions of cause and effect, which exist among explaining variables, are grasped.

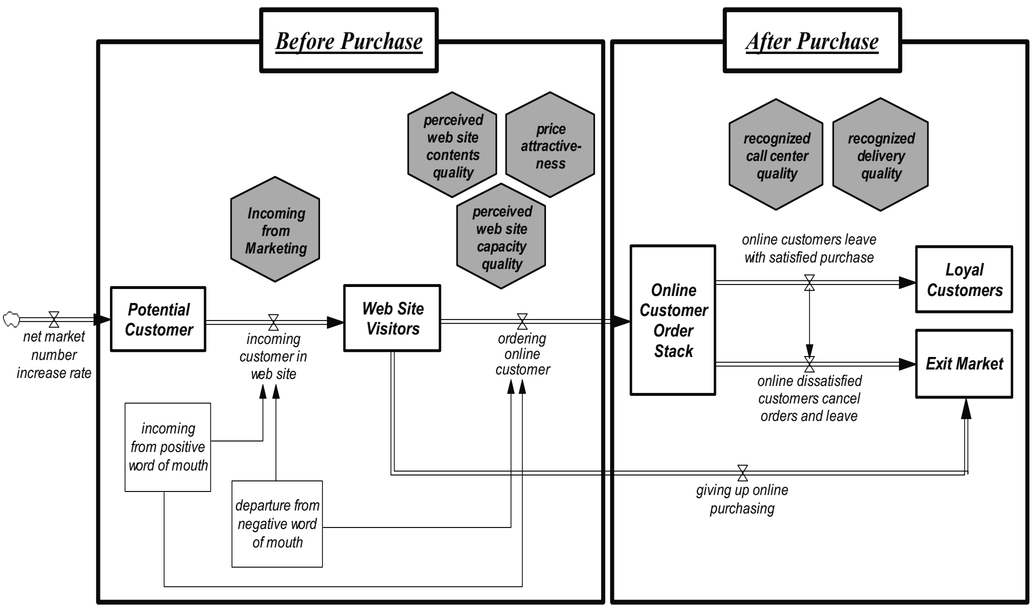


Figure 1. The system dynamics model of resource allocation decision making

Therefore, in this study, for the purpose of examining the series of such circulating causal relationships among strategic elements related to Internet purchasing, the system dynamics framework of the efficient decision making for resource allocation in Internet shopping mall is developed. VENSIM DSS Ver. 5.5, which is the tool for system dynamics simulation, is utilized to construct and analyze the model.

3.2 The expansion process of demand in pre-purchase step.

3.2.1 The system dynamics model of investment for internet advertisement and promotion

Bass, in his expansion model (1994), presents advertisements and promotional activities that stimulate radical demand, along with the word of mouth activities that can induce mimicking demand, as the political variables that attract customers in the process that potential customers visit the web site with the recognition of a product and brand.
When it comes to attracting customers to the web site and getting them involved in actual purchase, Internet advertisements and promotions, which stimulate radical demand in the Internet shopping mall, are more cost-effective and efficient than traditional media. They provide information on the internet shopping mall or their products, eventually deriving sales through bi-directional online communication. Furthermore, they are utilized to introduce new products of an internet shopping mall or promote purchase by providing customized information to existing customers via emails, and by contacting the customer continuously (Cleland & Robin S. 2000; Ducoffe & Robert H. 1996).

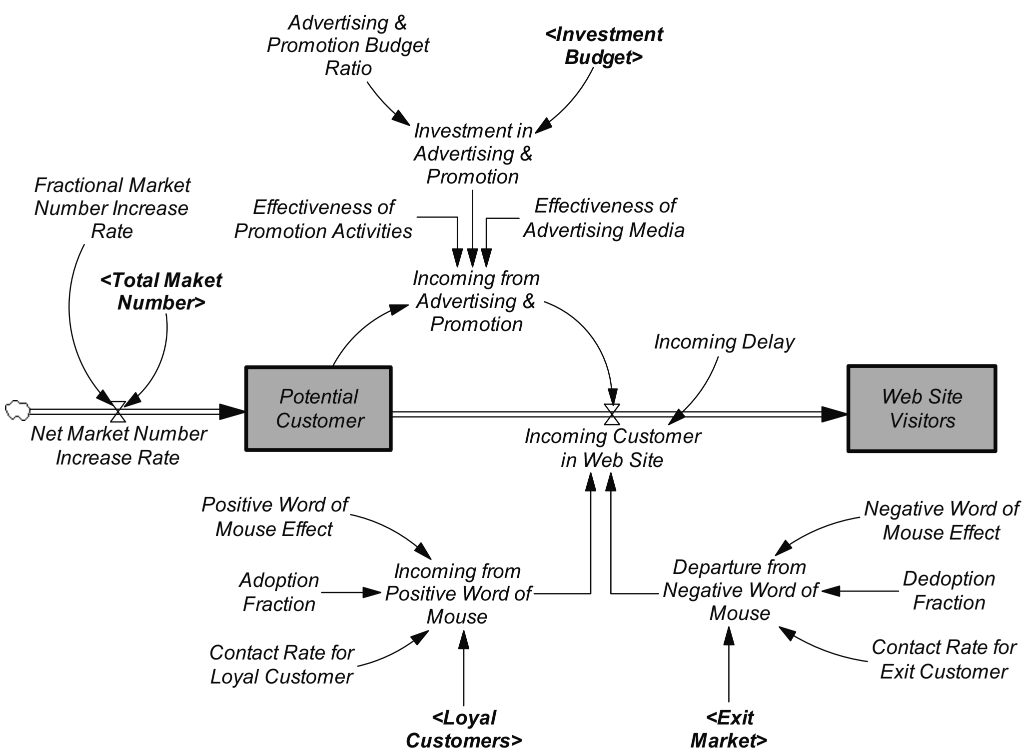


Figure 2. The system dynamics model of investment for Internet advertisement and promotion

Regarding word of mouth, as described in the literature review, the customers with previous purchase experience tend to introduce the shopping mall or products to other potential customers. In other words, satisfied customers will spread positive words, and those unsatisfied will spread negative words. And through these processes, customer inflow by positive word of mouth and customer loss by negative word of mouth is created (Godes, D. & Mayzlin, D. 2003).

Each auxiliary variable, which are used in the system dynamics model of this study, was measured by utilizing the example of an Internet book store, which is one of the most common forms of internet shopping mall, and these variables were applied to the actual model. And in the case where it is hard to draw concrete value, the variable values presented in existing theoretical study were used. Regarding the growth of the potential market, the types of growth are hypothetically divided in two different types for analysis. First, with the assumption that the overall market size of an internet bookstore makes a letter S shaped logistic curve, in the early stage, the market grows slowly, however, later as time flows, the market makes rapid growth, and in its maturity stage the growth gets slowed down making the typical S shaped market size. The second model assumes that the Internet bookstore market shows an exponential increasing pattern, meaning that the market grows rapidly every year with a regular ratio. The rapid growth ratio from this model may be able to explain the rapidly growing pattern of the Internet bookstore market but since it is more general that the market growth speed gets dull and slows down as time flows in reality, each of the above 2 assumptions on market growth was applied to subsequent analysis.

Regarding the efficiency evaluation on investment for advertisement and promotion, in order to measure the efficiency of on-line advertisement, such issues as how much traffic the internet advertisement has created, in what channels customers come across the information on the site, and what types of banner advertisement are being introduced to customers have to be grasped. Therefore, in this study, for evaluating the availability of advertisements, values provided from the selected internet bookstore, and the values from analyzing a log file such as 'hits', 'page views', duration of stay, sessions, and the number of visitors being the barometer for evaluating the efficiency of advertisement, are used. Also, the data of CPM (click per mill) and CTR (click through rate), both having relations to Internet advertisement, are used. For the availability of promotional activities, this study used measurement values acquired from customer reaction toward the promotional activities of the sampling company. And among the variables related to word of mouth, the probability of contact with loyal customers, which is the measurement variable for the positive word of mouth effect, and the probability of contact with non-purchasing customers, which is the measurement variable for the negative words of mouth effect, were applied with historical data from other previous theoretical literature. The previous literature suggests that the negative words of mouth have about 7.5 times more effect than positive word of mouth. And for the information of selection ratio and rejection ratio, values from previous literature were applied. The efficiency of positive word of mouth and negative word of mouth were constructed with nonlinear function and analyzed the degree of changes in values through sensitivity analysis.

3.2.2 The system dynamics model of investment on the quality of web system

It is the most important thing for an Internet shopping mall to provide faster and more stable system maintenance as a virtual retail shop under Internet based circumstance.

However, if the number of visitors or transactions for the web site increases, it creates more web traffic, causing the appropriateness of web server infrastructure to go down. And this, again, reduces Internet transactions due to the decrease in business attractiveness, resulting in a negative feedback structure. The negative feedback effects means that the overall structure of a sub-system circulating around a feedback loop is in the form of scattered mixture between some increase from positive effect and some decrease from negative effect, and eventually maintaining a stable system structure as time goes by. However, if profits from Internet business transactions are invested on web server, an improved web server infrastructure can play as the factor for revitalizing Internet business transactions by elevating the appropriateness of the server. Therefore, the operator of an internet shopping mall must commit to constant investment on the infrastructure of a web server in advance for making smooth transactions in the internet shopping mall possible(Donthu & Naveen 2001).

The following is the explanations of the system dynamics model on the quality of web system.

If the number of users searching or purchasing products in web site increase, the traffic of web site gets heavier, resulting in the increase of crowdedness in web site. This will cause the overload of web server capacity, considerably slowing down the loading speed and

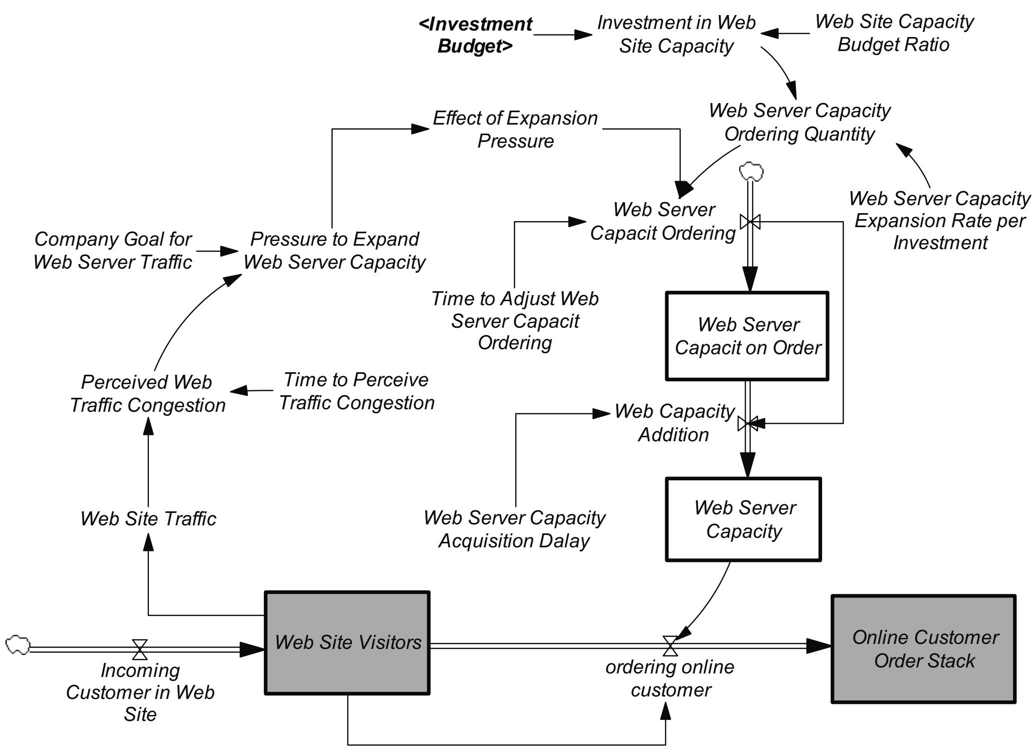


Figure 3. The system dynamics model of investment on the quality of web system

download speed of web site. Overloaded server capacity puts continuous pressure of investment on increasing more web server capacity as the traffic of customers in web siteincreases. And the administrator of web server in the Internet shopping mall has to make an investment decision on a web server by judging from the difference between the status oftraffic in current web system and the expectation of customers on crowdedness in the process of searching through or purchasing products from the mall. And depending on the difference or the directions between the degrees of web traffic crowdedness that customers feel actually and customers expect, customers have satisfaction or dissatisfaction toward their purchase from the Internet shopping mall. Customers who are satisfied with the speed or reliability of the web server system end up buying products or services from the Internet shopping mall, and customers who are not satisfied give up their purchase from the mall and end up using offline malls, or completely give up their purchase from anywhere.

Therefore, investment on web server lessens the gap between customer's recognition and their expectations on the web system, making the purchase environment amicable. However, the administrator of a web site needs to have a solid pre-management plan on traffic, since the investment related to the expansion of web server takes some interval time (Liu, C. & K. P. Arnett, 2000). Thus, it is essential for the administrators of Internet shopping malls to provide conditions in advance and timely fashion to customers that they can enjoy shopping through Internet under the circumstance of faster speed and more stability in the step of searching or purchasing.

3.2.3 The system dynamics model of investment on the quality of web contents

To convert simple site visitors of internet shopping mall into actual consumers, more useful and more reliable information has to be provided to them. In other words, it is essential not only to construct useful contents that can stimulate the interest of customers, but also to provide a systematically structured web site with systematic navigational structure in which customers can easily browse through. Therefore, the contents provided by the web site of the internet shopping mall have to be equipped with, first, the merchandising function introducing the variety of products to customers, secondly, the navigational function making easier product search possible, thirdly, the web design emphasizing external aspects such as visual appeal, overall website design, graphics, and effective color usage, and fourth, information security providing information reliance on purchase. The issue has been raised that these four aspects have to be individually analyzed with a more subtle and scientific approach. By doing so, customers will be experiencing feelings of satisfaction or dissatisfaction, and making a purchase decision or giving up purchasing, based on information provided by the Internet shopping mall (Dholakia, Utpal M. & Lopo L. Rego 1998; Huizingh, E. K. R. E. 2000).

In the system dynamics model of investment on the web contents of internet shopping mall, it is suggested that the environment of internet shopping has to be constructed so that it can provide more abundant and organized information to customers through the four variables which came from previous research (Moe, Wendy & Peter Fader 2001). Each influential variable decides the quality of web contents by the relative differences between the customers' actual recognition of the contents of an internet shopping mall by visiting it, and the level of quality that customers can accept through the four variables. The quality of contents in a web site like this becomes a very important standard for customers to judge the site by looking at the quality gap between actual recognition and expectation, thus, this quality recognized by customers becomes very influential element for decision making on purchase.

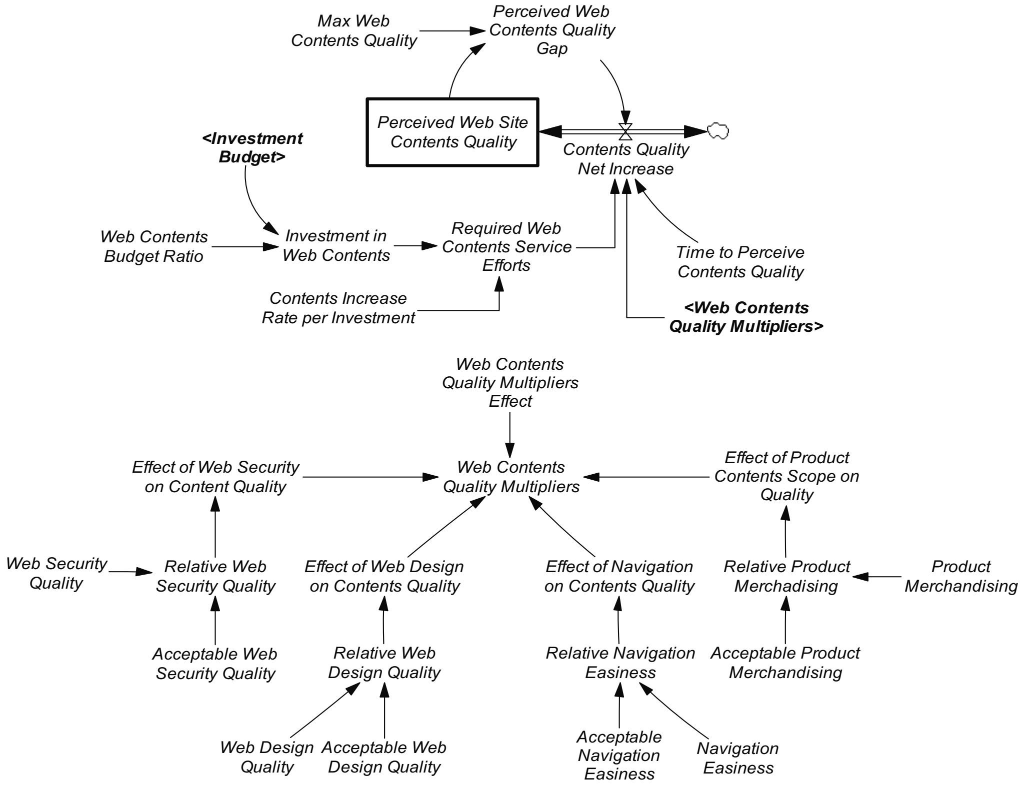


Figure 4. The system dynamics model of investment on the quality of web contents

In this study, as the materials for system dynamics simulation, values for four variables composing web contents are decided based on relative ratio between acceptable values and actual values. These values are analyzed by utilizing concrete values acquired from the sampled Internet bookstore's own consumer surveys. And for the anticipation level of what customers expect on the contents of the web, the average values of Internet bookstore industry in Korea from the survey conducted by KWPI (Korea Web Power Index) are used.

3.2.4 The system dynamics model of investment on price promotion

Price promotion is one of the important elements influencing customers' purchase decision in the internet shopping mall. According to Bailey's research(1998), the profit increase of a company has a positive effect on the investment related to the quality of service, and improved quality of service accelerate customer demand by providing an extra price premium on product or service. Furthermore, it is analyzed that improved quality of service boosts up the level of attractiveness customers feel about a product or service, bringing positive effect on the market share of a company. Moreover, the revenue increase of a company is followed by the cut down of cost due to its negotiation superiority and economies of scale. And the cost reduction effect brings down the price of products, making a low price policy possible (Smith, Michael F. & Indrajit Sinha. 2000). Such price differentiation strategy has a positive effect on increasing sales in the internet shopping mall by attracting more purchasing needs from customers. But, as examined in other previous studies, the level of satisfaction on price through price reduction policy is not an element influencing directly on the overall satisfaction level toward internet shopping mall, but it can influence a customer's purchase decision in the case that there is no product differentiation in each internet shopping mall. Therefore, rather than applying the same range of price discounts on the overall products in the internet shopping mall, the administrator needs to maintain the price strategy that can speed up product sales through such promotional activities as differentiated pricing policy depending on the types of customers, limiting the quantity of a products to be sold, and special pricing promotion for limited time.

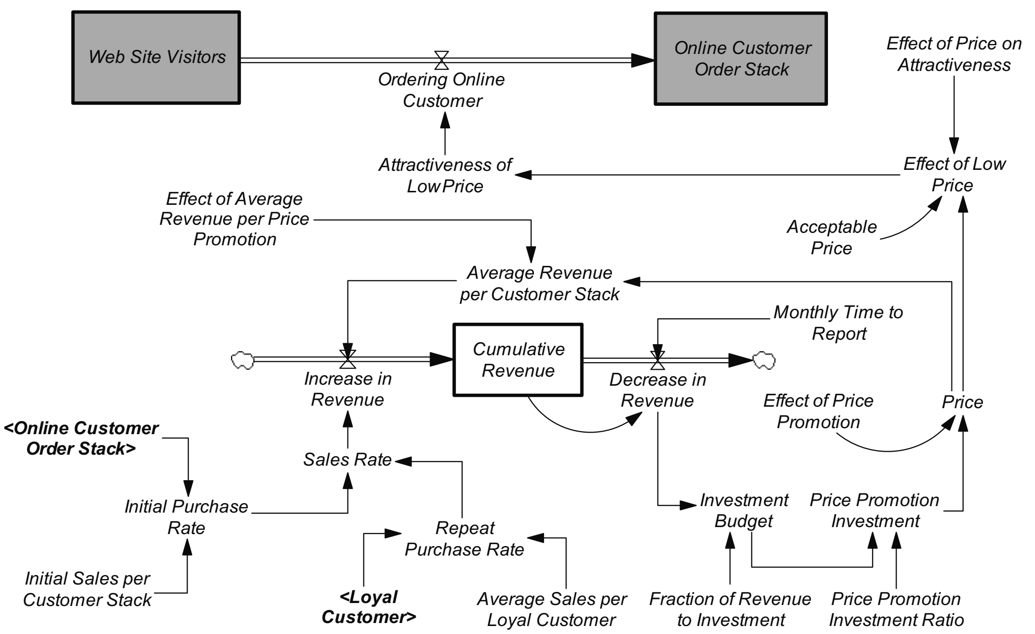


Figure 5. The system dynamics model of investment on price related promotion

Although the investment on price promotion plays a positive role in the profit structure of an internet based company, it also has negative aspects. As examined in literature review, the investment on price promotion functions as a factor to bring more purchases from the users of an Internet shopping mall, stimulating more sales. However, on the contrary, discounted pricing can be an element to worsen directly the profit of a company, because it causes customers to have a tolerance on continuous price reduction, so the internet based company has to maintain persistent price promotion to derive continuous purchasing from customers. Therefore, the policy maker of an internet shopping mall has to use the promotional policy with full consideration in positive and negative aspect of discounted price.

The investment on price discount means that some portion of the net revenue of a company is being utilized for price promotion, and through the width of the discounted price compared to the reference price on same products in other internet shopping mall, customers feel the attractiveness of the discounted price, stimulating customers' purchase. The effect of purchase influencing price discount is calculated by multiplying the price effect on the level of purchasing attractiveness with the value of actual price/acceptable price level. And, the price effect on the level of purchasing attractiveness is modeled in nonlinear function by applying Gutenberg- type price sensitivity function.

Furthermore, price discounts have a reverse function on the profit structure of an internet based bookstore. When the company revenues are calculated by multiplying total quantity of products sold and the sales price, the decrease in sales price at the same time leads to lower the accumulated revenues of a company. Thus, the administrators of internet shopping malls must satisfy their customers with appropriate pricing ranges and methods by grasping both the negative and positive aspects of discounted price.

3.3 The process of demand expansion after initial purchase

Customers evaluate the internet shopping mall they use depending on their purchasing experiences from the mall such as how fast and safely the delivery of product they ordered is made and how conveniently problems regarding their ordered products can be resolved. Based on evaluation via their shopping experiences, customers decide whether or not they should revisit to repeat their purchase. Therefore, it is not necessarily possible that customers are satisfied with the internet shopping mall just because it had a promotional event one time and built a good purchasing environment on the website. Only when all the necessary elements customers want are operated together in harmony, will customers' full satisfaction be possible.

3.3.1 The system dynamics model of investment on the service quality of delivery

According to the market growth model by Membrillo et al., (2002), the more the customer orders are received the more there will be delays of product delivery, diminishing the market attractiveness of a product or service. And the increase in the delay ratio in product delivery adds pressure on the company to expand investment in additional delivery capacity. Thus, in the same model, they insist that companies have to satisfy customers by minimizing delay of product delivery, and utilizing their capacity efficiently. Also, in the studies by Oliva & Sterman(2001) and Mentzer et al., (2001), as customers place more and more orders, the backlogs of placed orders increase, needing the expansion of delivery capacity, eventually bringing the feedback effect that performs delivery smoothly through the expanded delivery system capacity which is added after some time interval.

In the case of an Internet shopping mall, the more customers make their purchase on line, the more delays of deliveries there are for the portion that exceeds current delivery capacity. Even though the delays in product deliveries keep adding up, it happens that Internet based companies and their belonging market can recognize this only after some time. Furthermore, even at the point of time Internet based companies realize the delays, there is already a big gap between the delivery service customers experience and the delivery service the company aims for, due to the accumulation of overloaded orders from customers. Then, it will make the customers' level of dissatisfaction on delivery service increase, causing the cancellation of orders or the decrease of potential orders. That is, the loop related to delays in product deliveries has a negative feedback effect, so orders will decrease more and more after some point. However, delays in deliveries give the administrator of a internet shopping mall more pressure on expanding delivery capability and capacity, thus, some portion of company profits is invested in expanding the delivery system. In fact, the pressure effect of expanding the facilities for delivery service is modeled by indicating in a nonlinear way the difference between the actually recognized delay of product delivery due to the increase in orders being placed and the duration of product delivery that the Internet shopping mall company is aiming for (Sterman, 2000).

Delivery capability expanded from the re-investment on the delivery service processes orders efficiently and provides satisfactory feelings to customers by bridging the gap between what customers expect and what they experience. By doing so, it influences customers' decision on re-purchase by boosting up the loyalty of customers towards online purchasing (Bienstock et al., 1997).

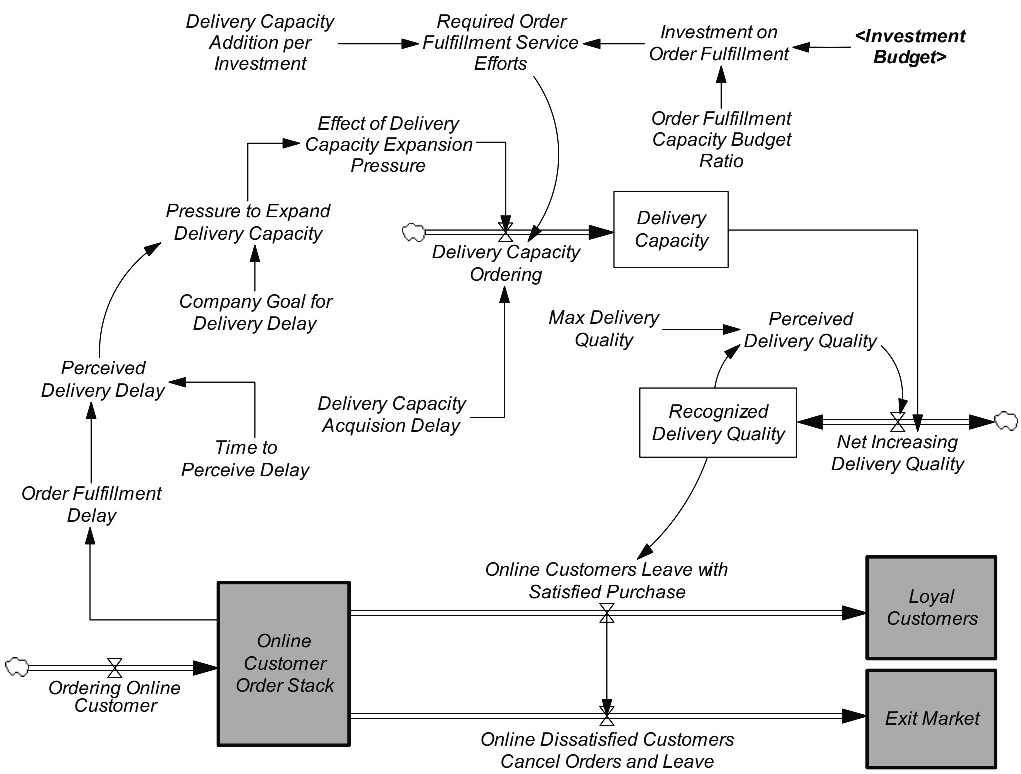


Figure 6. The system dynamics model of investment on the service quality of delivery

3.3.2 The system dynamics model of investment on the quality of customer support service

An Internet shopping mall has to think deeply about strategies and operations that can provide customers with contact opportunity on some meaningful benefits and make them happy. It is the customer support center which is the closest contact point improving relationships with customers by listening to customers. The performance of the customer support center, which is the contact point between customers and company, depends on how it satisfies customers with a reasonable amount of cost, and prevents them from staying away from the company. The customer support service team processes the complaints or the questions from customers by utilizing the resources related to the service with limited amount of budget. Then, the way and delay level of responding to customer complaints and questions influences customers' confidence on the Internet shopping mall, and ultimately affect the level of customer satisfaction after their purchase. Therefore, it is essential for Internet based companies to be equipped with a real time customer support system that can respond to complaints and questions in a timely and kindly manner (Anton, J. et al., 1999).

As the number of customers placing orders online at an Internet shopping mall increases, more various questions or complaints regarding the purchases or the deliveries of products are created. And these questions or complaints are resolved through the customer support center of the Internet shopping mall, the information desk of web based call center, and the

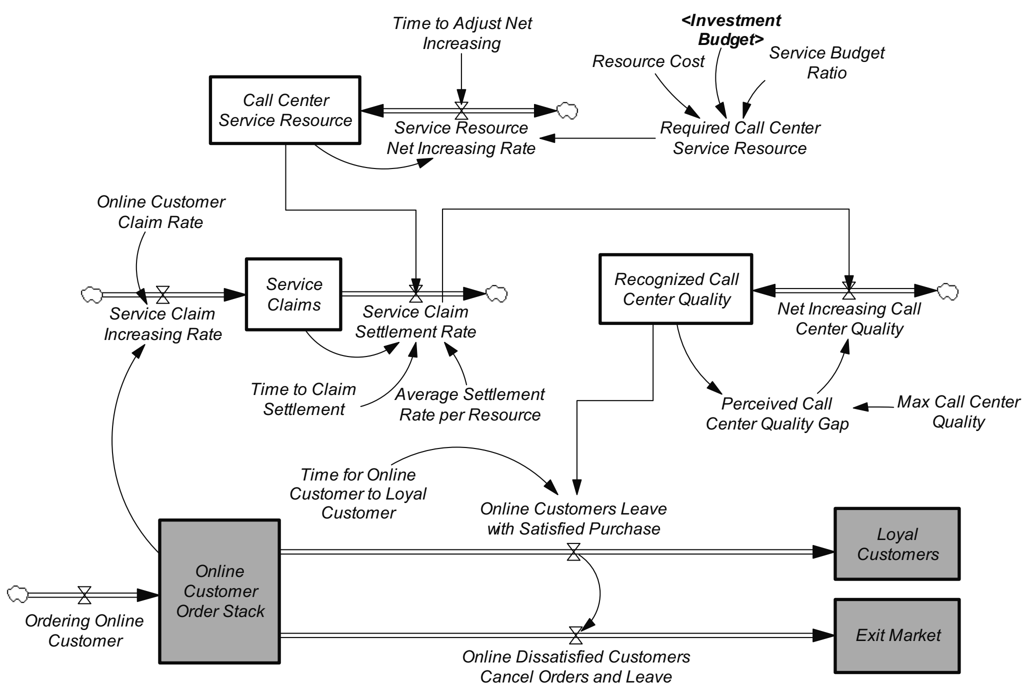


Figure 7. The system dynamics model of investment on the quality of customer support service

FAQ (Frequently Asked Question) section of the site. There are some differences between the service level customers expect regarding the management of complaints and questions and service level provided actually by the internet shopping mall. According to the level of such difference, the service quality of call center that the customers of the mall feel about will be differentiated. The quality of call center influences the level of satisfaction after their purchase, further, affects customer loyalty. Therefore, the administrators of Internet shopping malls need to respond to customers' request in timely fashion by utilizing the human and physical resources that can process efficiently the service claim related to their consumers (Ward Whitt, 1999).

4. Simulation analysis and its result

4.1 The validity of the system dynamics model

Before analyzing the decision making model of Internet shopping mall, first, the validity of the model has to be confirmed. According to the study of Barlas (1989), the method of evaluating the validity of model can be divided into two general approaches. One is the validity of model structure and the other is the validity of model behavior.

First, in the validity of model structure, after the conceptual modeling was constructed based on various theories and research results from previous literature regarding the purchase decision in the internet shopping mall, the structural validity and boundary appropriateness were verified by going through several discussions with many practical managers, followed by amending the structure of the model. Also, in this study, the unification of measurement unit was achieved by conducting simulations for 60 months along with according the unit of measurement from the numerical formulas of each variable at the same time. In the validity of model behavior, the pre-tests on each partial loop were conducted to reflect the elements from the pattern of purchase decision in the Internet shopping mall such as the symptoms of problems that can be witnessed in real world, the behavioral pattern, the behavioral change in each step, and the fluctuation. And, the initial value of the model is adjusted to arrive at the balancing status – a certain point where the condition of simulation reaches the stabilized step through the connection of loop in the overall model. By doing so, the conditions for the reproducibility and normality of model behavior were satisfied. Also, by conducting sensitivity analysis on each LOOKUP function, the validity check on each function is carried on at the same time.

The most important and the most influential LOOKUP function among all the LOOKUP functions used in this study is the function of price discount on the level of attracting purchase. The price sensitivity function of Gutenberg type is used for the LOOKUP function. The hypothesis suggested in the Gutenberg model is that if the price gap between the company's own product price (Pi) and average competing price (Pi*) is small, such difference in pricing have a relatively low influence on the quantity of company products sold or the market share of the product.

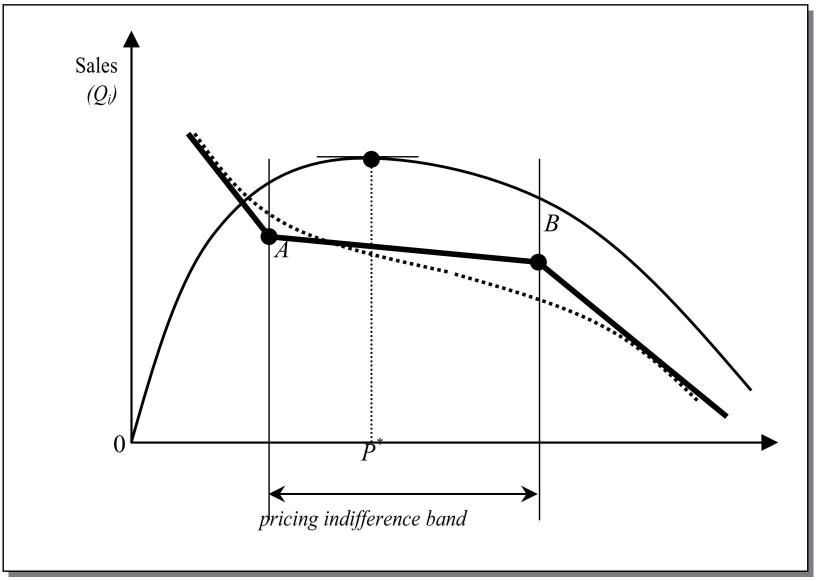


Figure 8. Non-linear price response function (Gutenberg Model)

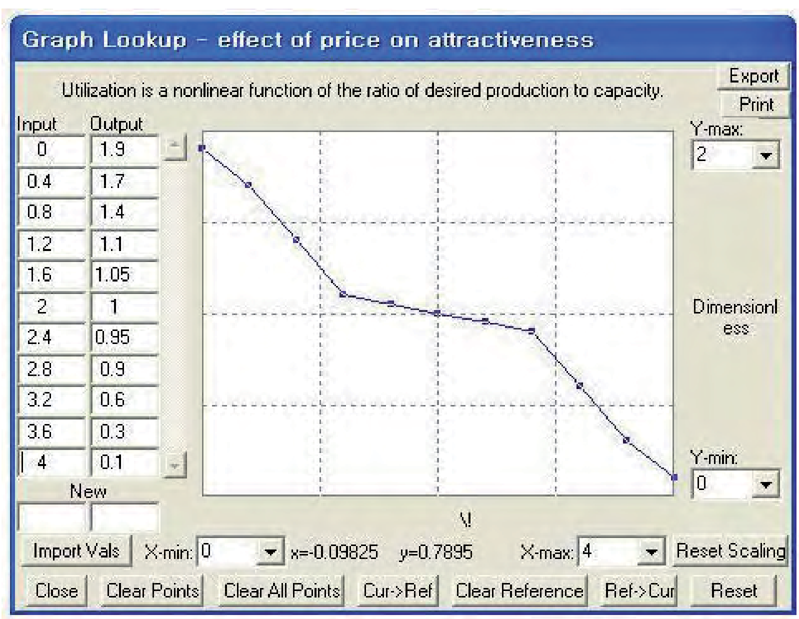


Figure 9. LOOKUP function of the effect of price on attractiveness

In the Gutenberg model, the section between A and B is the area of price by which customers' purchasing decisions are not influenced. The model assumes that customers in this section will keep purchasing the product or the service of the company with the intention of paying extra money. This assumption is only possible when current customers have favorable feelings about purchasing the product of the company and there exists a switching cost for customers to change their preference. Therefore, when the price gap is not big, customers mostly tend to keep purchasing products they currently use.

Thus, this study analyzed the interactive relationship between price discount and the quantity of products purchased by customers by the Gutenberg model. In other words, customers tend to show the increase of their purchasing intention when they recognize more significantly transactional effectiveness – the difference between internal reference price and actual sales price which is formed through the price comparison with other internet shopping malls. In the sensitivity analysis for the influence of price discount on the level of attracting purchase, the effect of discounted price on customers' buying decision and the decision making related to the overall resource allocation is appeared to be not much significant. However, it is found that depending on the partial changes of the nonlinear relation of LOOKUP function, the values of overall stock variables and flow variables change bit by bit. But it is also found that this changing ratio lies within an acceptable range, not having major influence on decision making.

4.2 Simulation analysis

When analyzing the company in the example, the simulation is conducted for 5 years (60 months) with the unit of analysis in a month, considering the environment of internet market, changing so fast more than ever. In the analysis for the example company, the cases are divided in two assumptions for the analysis and comparison, one being the growth pattern of internet bookstore market in (A) S-shaped logistic curve and the other being (B) in the form of constant increasing growth. In the case with the assumption of the growth pattern of internet bookstore market being an S-shaped logistic curve, the assumption means that there is a negative feedback structure for the overall size of internet bookstore market not to be able to grow continuously. Under the basic assumption of Bass's model of expansion in demand, the market grows due to the definition feedback loop at the early stage. However, as time passes, the market growth gets oppressed by the strengthening of the effect of a negative feedback loop (Bass, 1994). Under the case that the overall size of the market is in the form of S-shaped logistic curve due to the limit of growth, the demand of the market grows rapidly at the early stage due to the effect of the limited number of potential users and then later, the demand decreases due to growth limits. Namely, when the overall market size is called M and the number of actual consumers at the point of time t is called $n(t)$, the number of potential users left is $M - n(t)$. And assuming the conversion ratio of potential consumers to actual consumers as c, at the point of time t, the number of converted consumers from the potential to the actual is $n(t) \times \{[M - n(t)] / M\} \times c\Delta t$ and $dn(t)/dt = c \times [M - n(t)/M] \times n(t)$. When $n(t)$ is calculated through this, it is as following formula (1).

$$n(t) = \frac{M}{1 + [(M - n_0) / n_0] e^{-ct}}, \quad t \geq 0 \tag{1}$$

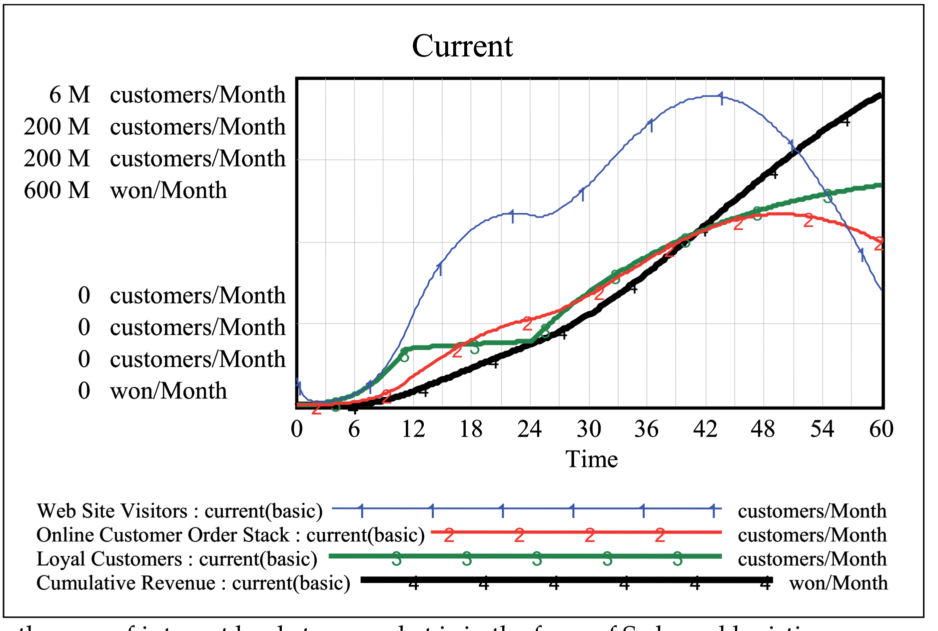
In the system dynamics model with the assumption of the overall market size of internet bookstore being in the form of S-shaped logistic curve with the basis of Roughgarden's study (1998), the market growth rate of an internet bookstore is calculated by multiplying the market growth rate and the overall market size. And, here, the arithmetic formula for the overall market size is calculated by summing all the numbers of potential consumers, the site visitors, the online consumers, the loyal customers, and those who gave up their purchase in the online market. And the growth rate of internet bookstore market is analyzed by using the S-shaped LOOKUP function. Through a formula such as the above, the model is designed in the way that the internet bookstore market grows in rapidly in the early stage, then later after some point, the growth rate of the market lessens or stops with no more expectation of further growth.

And another analysis is conducted on the model assuming that the internet bookstore market maintains continuous growth in the form of constant increasing function, overcoming its limit. In the case with the assumption of the internet bookstore market being in the form of constant increasing growth, it is assumed that the expansion in demand grows with no limit due to the infinite potential customers. In the study by Kirkwood (1988), the number of actual buyers $n(t)$ at the time of t is calculated with the assumption that the number of actual buyers during the time $t + \Delta t$ being $n(t) + n(t)\, c\, \Delta t$.

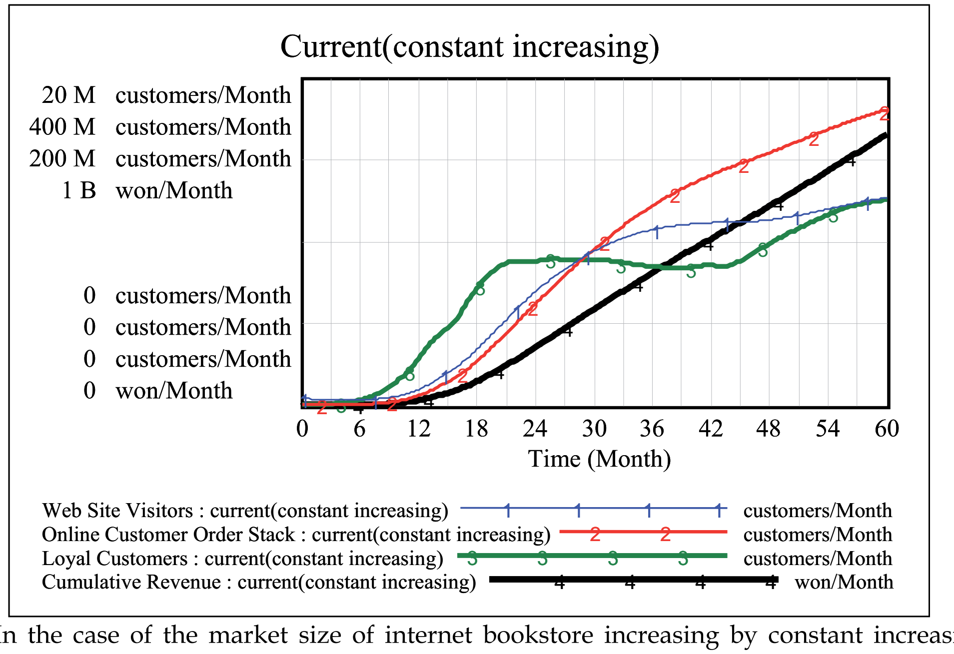
$$n(t) = n_0\, e^{ct}, \quad t \geq 0 \tag{2}$$

With having the study by Kirkwood (1998) as the basis, the growth rate of internet bookstore market in the assumption being the market constant increasing growth is calculated by multiplying the potential size of the market and the market growth rate. And in this case, the growth rate of internet bookstore market is modeled by having it through STEP function with the basis of future growth rate of internet shopping market, which was used in 'the analysis and the prospect of domestic internet shopping market' by KISDI(Korea Information Strategy Development Institute) and with the analysis of historical growth rate information (1999~2004) on domestic internet bookstores in Korea.

In the case with the assumption that the size of the internet bookstore market is in the form of an S-shaped logistic curve (A), the following are the results from the analysis of important stock variables based on the data of an exemplifying company. That is to say that the number of visitors for internet bookstores shows rapid growth in the early stage, then around the 20th month, shows the symptom of a temporary lessening of growth speed, however again in the 26th month, it shows rapid growth again. Also, after reaching to the maximum point around the 43rd month, it turned back to the tendency of rapid decrease. The number of consumers placing orders with the online bookstore shows gentle growth from the initial point, however around the 50th month, shows the tendency of going back to decline. The number of loyal customers to the internet bookstore, in its early stage, shows the tendency of continuous increase, however around the 11th month, the tendency of increase is lessened, showing its status as the growth in the number of loyal customers being stopped, and around the 24th month, showing its tendency of increase. Accordingly, the accumulated profits of internet bookstore show continuous tendency of increase with a rather declining tendency around the 80th month. And in the case with the assumption that



(A) In the case of internet bookstore market is in the form of S-shaped logistic curve



(B) In the case of the market size of internet bookstore increasing by constant increasing growth

Figure 10. The stock variables of the internet bookstore case

the market size of internet bookstore increasing by constant increasing growth (B), by looking at the results from the analysis of stock variables in the exemplifying company, it isfound that the number of site visitors constantly increases until the 36th month, however, starting from the 36th month, the gentle increase settles in. The number of consumers, placing orders with internet based bookstore, appears to be increasing and then startingaround the 20th month, shows radical growth, which maintains its growing tendency for a while. Regarding the loyal customers of internet bookstore, it shows the pattern of radical increase in early stage and then stop its growing pattern briefly around the 20th month, then showing the gentle decline until the 42nd month and then going back to the pattern of radical growth. Thus, it seems that the accumulated profits of internet bookstore follow continuously the increasing pattern as well.

This pattern - that the values of the stock variables for some duration falls all at the same time, stagnate without going through the increasing pattern and then going back to the pattern of increase – is caused by the investment delay on the delivery service, which is one of the service quality elements after purchase, and the service capability of customer support. In other words, as the number of customers placing orders increase, it is possible to provide continuous services to the customers through the existing system of delivery service and customer support service in early stage, however from certain point of time, it becomes that exceeding number of orders is not matched with the existing system, resulting in not being able to respond appropriately to some of the requests by customers who then end up having dissatisfied experiences with the internet bookstore. The administrator of internet bookstore, realizing the lack in the capability of its service, tries to provide the quality service by putting additional investment on delivery service and customer support service. However since it necessarily involves with the delay in expanding the service capacity, the number of loyal customers does not increase until expansion in the service capacity is fully done. Therefore, the administrator of an internet bookstore has to arrange the proper environment for customers to be satisfied and then become loyal customers. And it means that securing the service capacity fully in advance through the estimated projection of demand on the delivery and customer support service is the important element for satisfying customers and considering the profit of the company at the same time.

4.3 The analysis of the most optimized portfolio for providing the best profit ratio to the internet bookstore

The primary purpose of this study is, from the perspective of the administrator of internet bookstore, to answer the question of how to maximize the profit of a company after allocating the resources of a company in most efficient way by using the methodology of system dynamics. In other words, the study is to verify, from the perspective of profit maximization, what the most optimized portfolio is as to investment alternatives. For this purpose, the investment alternative, providing the most optimized profitability to the internet bookstore, was compared by adjusting the investment ratio of 6 investment alternatives, which were used in the previous section of the study. Among the various combinations of the investment alternatives except for some of extreme cases, about 36 alternatives were compared for analysis. From 36 alternatives, three alternatives, providing the most optimized profitability to the internet bookstore, were derived for the case with the assumption that the size of internet bookstore market is in the form of S-shaped logistic curve and the case with the assumption of it being in the form of constant increasing growth. Thus, 6 alternatives are derived, they are as follows.

Alternative / *Investment Control Variables*	*(A) In the case of S-shaped logistic curve*			*(B) In the case of constant increasing growth*		
	Alternative(A)	Alternative (B)	Alternative (C) (Optimal)	Alternative (D)	Alternative (E)	Alternative (F) (Optimal)
Internet Advertisement & Promotion	20	15	10	15	10	10
Web System Quality	15	20	20	20	15	15
Web Contents Quality	10	10	10	15	20	20
Price Promotion	20	15	10	10	15	10
Delivery Service Quality	20	20	25	20	20	25
Customer Support Service Quality	15	20	25	20	20	20

Table 3. Investment portfolio of Strategic Alternatives

4.3.1 Strategic investment alternative (A)

Strategic investment alternative (A) is the one investing mostly on internet ads or promotions, discounted price, and delivery service under the condition with the assumption that the size of internet bookstore market is in the form of S-shaped logistic curve. When the results of analysis are looked into, it has a lot of site visitors and purchasing customers in early stage, however, it has a difficulty of increasing the number of visitors or consumers continuously. That is because there is limit for making the constant growth in the number of customers due to the decline of investment on the web server that can cover a lot of visitors or consumers in early stage, resulting in the increase of traffic. Also, this alternative is evaluated as being unable to fulfill satisfaction of increasing loyal customers continuously due to the lack of investment in the customer support service.

4.3.2 Strategic investment alternative (B)

The strategic investment alternative (B) is the one with lower investment ratio in internet ads and promotions along with price reduction and, instead, with relatively higher investment ratio in web server systems and customer support systems, under the assumption that the size of internet bookstore market is in the form of S-shaped logistic curve. It shows much higher profitability than the strategic investment alternative (A). Looking at the results of system dynamics in alternative (A), it shows the pattern in that there are less visitors in early point than the alternative (B), however in later stage, it has a more growing number of visitors constantly than the alternative (A), securing about two times more number of customers than the alternative (A).

Furthermore, when it is evaluated based on the total profitability, it has about 1.3 times more profits than the alternative (A) by having its growing ratio of loyal customers continuously increase. It is evaluated to be a good investment alternative in the sense that it has the construction of the stable web server, and more smooth delivery service with its capability of being able to come closer to customers. However, in the sense that it lacks in securing customers at the initial stage, and actual consumers, it is viewed as rather insufficient alternative. Thus, it is a good strategy only when used properly in the stage of market maturity and maintaining some level of market share already won.

4.3.3 Strategic investment alternative (C)

The strategic investment alternative (C), being the most optimized investment portfolio under the condition with the assumption that the size of internet bookstore market is in the form of S-shaped logistic curve, has about the same level of investment ratio with the alternative (B) except for the fact that it has less investment ratio on internet ads and promotions along with price reduction by about 5%, and instead has 5% more investment ratio on delivery service and customer support service. Although its initial profits are less than other strategic investment alternatives, in the long term, it provides the most optimized profit structure. The alternative (C) is the one with concentrated focus of investment in customer support service after purchase. Even if it lacks in securing initial customers, it is the strategy, viewed as the very effective investment alternative that can convert a growing number of site visitors and consumers to loyal customers efficiently. When examined in more detail, more investment in the quality of service after purchase makes customers have higher expectations that the quality of delivery service and customer support service is very excellent. And by doing so, it can increase the level of repeated purchases of customers. Also it can boost up customer loyalty after purchase by providing more convenient and kindlier customer support through the expanded delivery service, and support service, and by actually making deliveries in a timely and accurate fashion. Thus, it shows the 1.5 times more increase in the number of loyal customers than the alternative (B). The phenomenon such as this reflects that the expansion of investment in delivery service and customer support service is becoming the very important element in the profitability of internet shopping malls as the variable that can attract general consumers to be its loyal customers and at the same time as the variable that can increase the repeat purchase ratio, under the circumstance that the ratio for repeat purchase is being raised as an important issue due to the growing tendency of an internet shopping mall market despite a recent slow down of the internet oriented market. However, the alternative (C), just like the alternative (B), also is viewed as an alternative lacking in attracting site visitors or buyers at the initial point. Thus, this alternative is considered to be the one that can be applied only when the market of internet bookstore is in its growing phase or maturity phase as well.

Therefore, the most optimized investment portfolio, under the condition with the assumption that the size of internet bookstore market is in the form of S-shaped logistic curve, has its investment in the order of 'delivery service and customer support service > web server system > internet ads and promotions along with price reduction'. And it is analyzed that this provides the most profits for the internet bookstore.

4.3.4 Strategic investment alternative (D)

The most optimized investment portfolio in the condition with the assumption that the size of internet bookstore market increases constantly shows rather different result than the investment strategies in the condition with the assumption that the market size of internet based bookstore is in the form of S-shaped logistic curve. First, the strategic investment alternative (D), which is one of the most optimized investment alternative portfolios, has the same investment pattern as the alternative (C). It is the alternative with rather higher investment ratio in web server systems, delivery services, and customer support services. This alternative has an increasing effect on initial site visitors due to the investment increase in web server; however, it shows a pattern of the increasing ratio slowing down as time passes. But since it has lower investment ratio in price reduction, internet ads, promotion along with promotional activities, and the contents of web, it has difficulty securing initial buyers. However, as the number of visitors and consumers increase, it appears to have higher frequency for conversion from simple consumers to loyal consumers due to the fact that the quality of rich fundamental service and infrastructure such as web server, delivery service and customer support service gets better, in which they had investment in at the initial stage. Thus, as time passes, the profit scale of an internet bookstore shows the pattern of gradually growing.

4.3.5 Strategic investment alternative (E)

The strategic investment alternative (E), which is one of the most optimized investment alternative portfolios in the situation with the assumption that the market size of internet bookstore increases in the form of constant increasing pattern, is simply the politic alternative with reduced investment in the internet ads, sales promotional activities, and the web server, and instead increasing the investment in web contents and discounted price, compared to the alternative (D), while maintaining the same range of investment ratio for delivery service and customer support service as the alternative (D). In other words, this alternative is made for the purpose of promoting the securing the initial customers, which is the weakness of the alternative (D) by strengthening the investment in web contents and increasing the investment ratio in discounted price. Examining the result of system dynamics, there seems to be no customer-attracting-effect at the early stage by increasing investment ratio in discounted price and web contents. However, after some point of time later, it shows the pattern of radical increase in the number of site visitors and consumers. This indeed means that the investment in web contents takes some time for attracting customers, thus, as time passes, radically increasing the number of consumers due to the expansion of investment in price reduction policy and web contents despite of the fact that these two investment alternatives seem to have no effect on increasing customers in early stage. Also, the expansion of investment in delivery service or in loyal customers, who have a tendency of increasing radically in numbers after some point of time, is viewed as the one with the contribution of promoting the brand recognition of the internet bookstore in some parts by providing more stable delivery service to customers.

4.3.6 Strategic investment portfolio (F)

The strategic investment alternative (F), which is the most optimized investment alternative portfolio on the condition we make the assumption that the size of internet bookstore market increases in the form of constant increasing growth, is the politic alternative with reduced investment in some portion of price reduction, instead expanding investment in delivery service, while maintaining the level of investment ratio on customer support service and web contents when it is in comparison with the alternative (E). In other words, this alternative provides the most optimized profitability to internet bookstore by reducing the investment in price reduction a little and by increasing the investment ratio on delivery service instead. Examining the result of system dynamics by this alternative, it has less initial effect on attracting site visitors than the alternative (D), however, it has a better effect on attracting initial visitors and securing actual consumers than the strategic investment alternative (E). On condition we make the assumption that the size of internet bookstore market increases in the form of constant increasing growth, the issue on the importance of investment in web contents is raised. Also, the alternative continuously secures loyal customers and purchasing consumers by expanding the support for delivery service and customer support service. It has less growth rate of loyal customers at the initial stage than the alternative (E), however, as time passes, the level of increase gets much bigger. Furthermore, in the aspect of company profitability, it eventually provides about 1.5 times more profits than the alternative (E) by continuously boosting up the profitability of the internet bookstore.

As a result of the simulation analysis, it was found that the optimal resource allocation portfolio providing maximum profits to the Internet bookstore involves large-scale investment on delivery service and customer support service which are the key factors for post-purchase customer satisfaction, regardless of the growth pattern or size of the Internet bookstore market. Consequently, from the above analysis, the investment ratio of resources for the profit maximization of an Internet bookstore was drawn.

As examined so far, on condition we make the assumption that the market size of internet bookstore increases in the form of constant increasing growth, the best combinations of investment alternatives are in the order of 'delivery service > customer support service, web contents > web server > internet ads and promotion, price reduction' for providing the most profits to the internet bookstore. Therefore, summing all the results so far, allocating more investment in the quality of service, that can provide satisfaction to customers, such as delivery service, and customer support service tend to provide the most profits to a company even if rather different investment portfolios are shown, depending on the market condition of an internet bookstore. Furthermore, things like building an additional web server and strengthening the contents of the web are other variables, making the purchase smooth. Although price reduction, which is one of the strategic variables and has been utilized by internet based bookstores, appears to have some effects on securing customers at the early stage of the market, it is analyzed that the effect is not persistent. And the price reduction is the variable with both sides of profit growth by securing customers and profit loss by reducing the price. Therefore, the administrator of an internet based bookstore has to operate the price reduction policy with a proper method in an appropriate ratio.

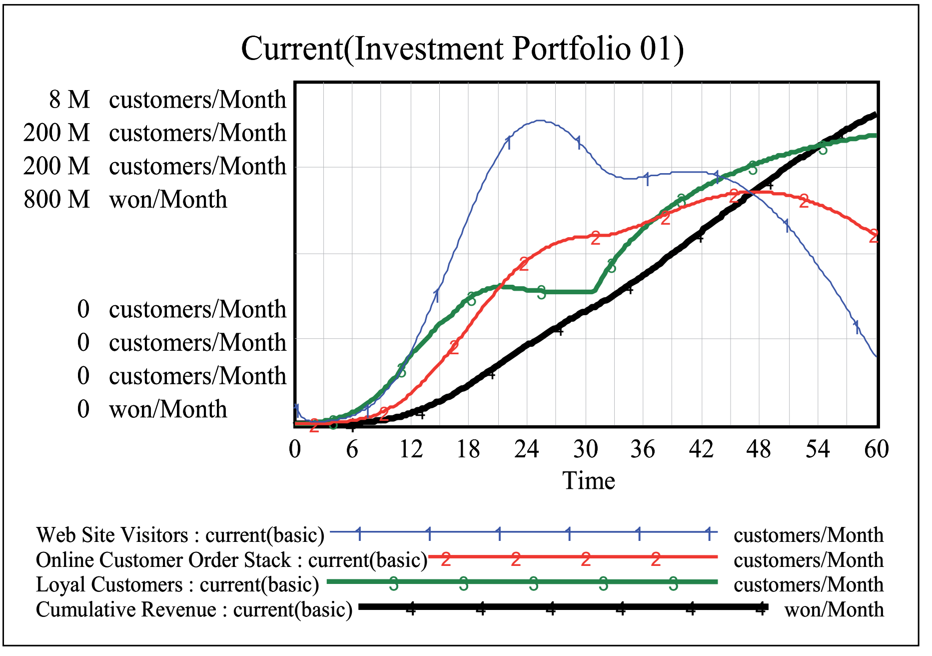


Figure 15. Optimal Investment portfolio(Strategic Alternative 1)

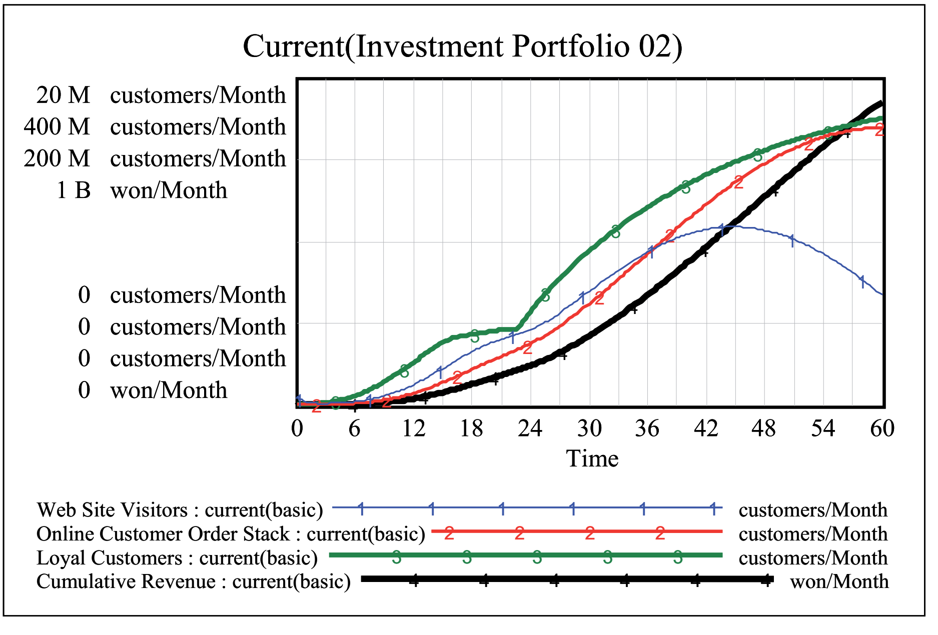


Figure 16. Optimal Investment portfolio(Strategic Alternative 2)

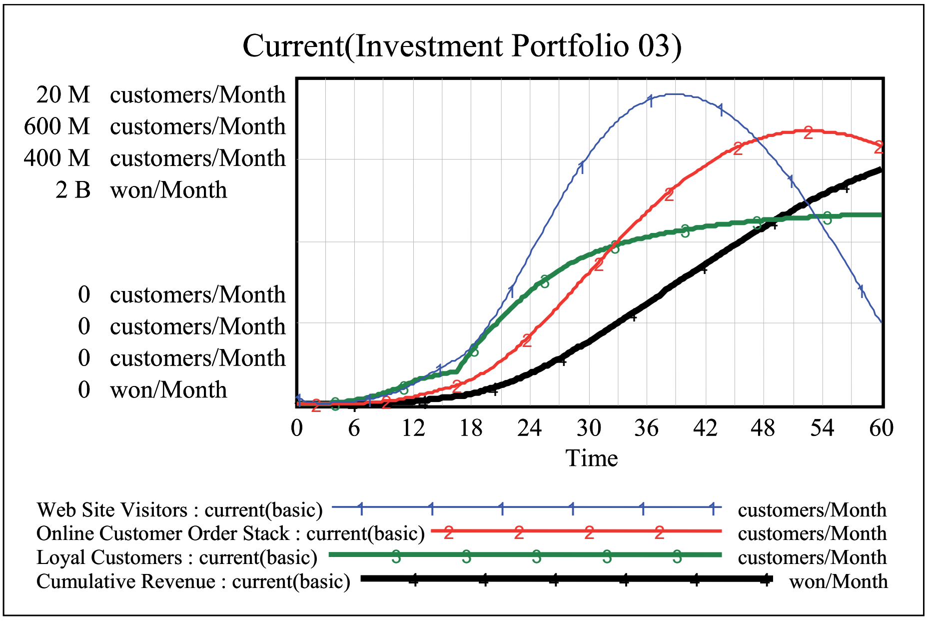


Figure 17. Optimal Investment portfolio(Strategic Alternative 3)

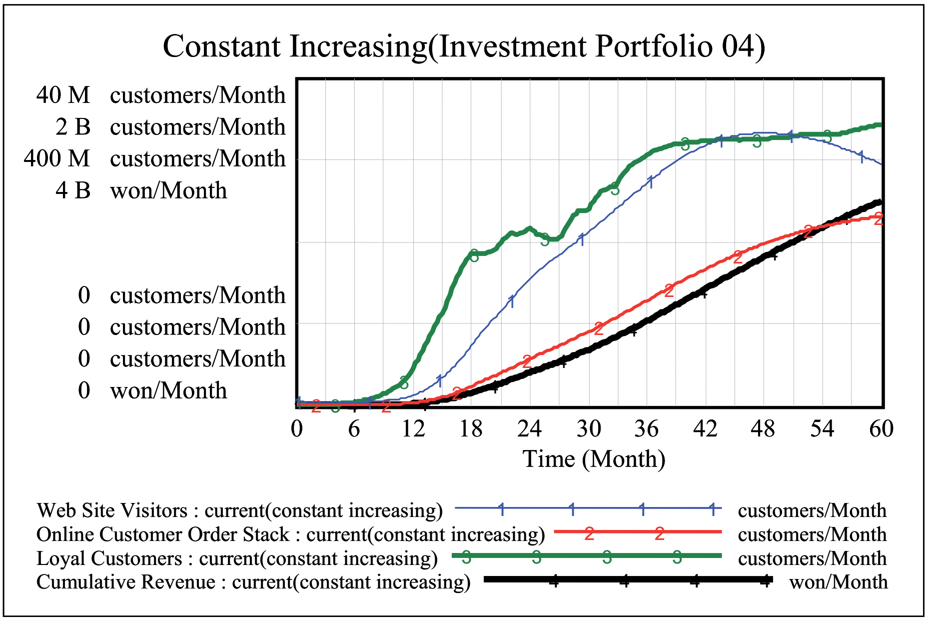


Figure 18. Optimal Investment portfolio(Strategic Alternative 4)

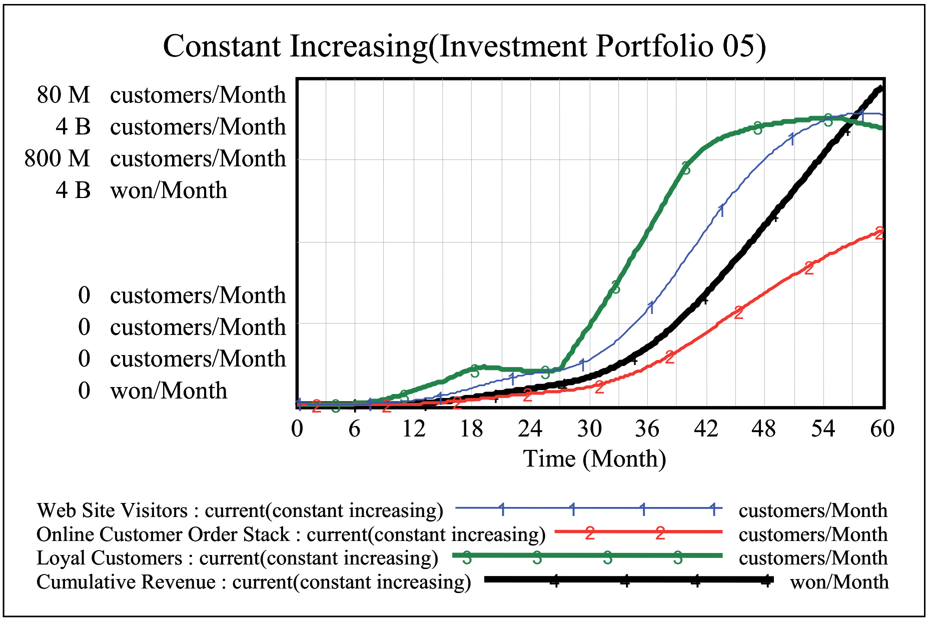


Figure 19. Optimal Investment portfolio(Strategic Alternative 5)

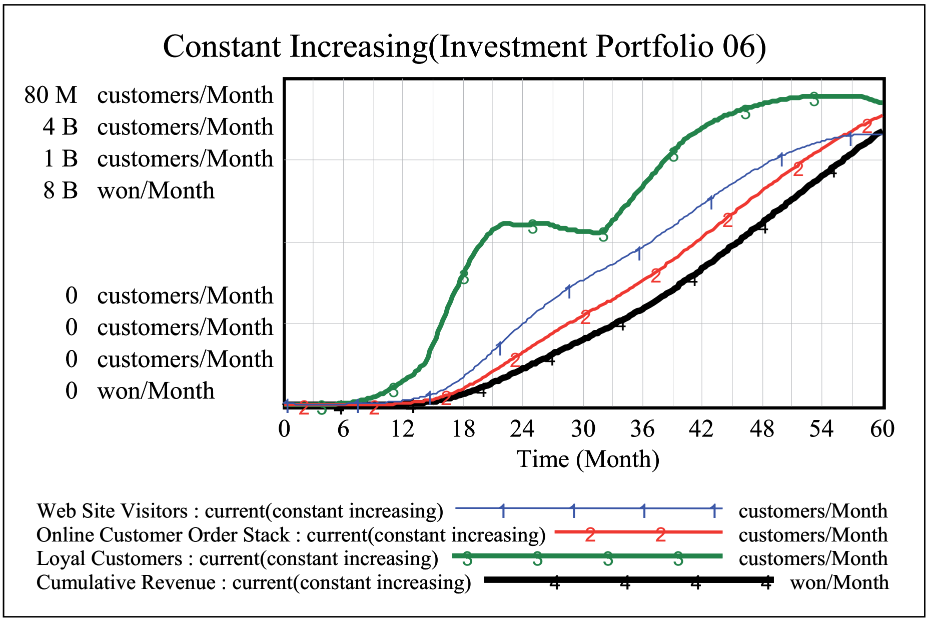


Figure 20. Optimal Investment portfolio(Strategic Alternative 6)

5. Conclusion and upcoming research direction

Through the study, 6 variables for interactions between causes and effects are found, related to the profit maximization of an internet based company in management aspect from the internet bookstore, which is one of the most common types of internet shopping malls. And by connecting all the variables in complex, the map for the cause and effect is systematically constructed. Furthermore, by verifying the necessary information of system dynamics model for the purpose of testing the resource distributed decision making model, it made the resource distributed decision making possible. Based on these contents, the relation between the variable, related to the level of customer's purchase / loyalty in the internet bookstore, and the resource distribution decision making is able to be witnessed.

Conclusively, based on the comprehensive examination of the results, this study provided a framework for dynamic resource allocation decision-making, and proposed a management strategy which allows consumers to shop under a more favorable environment, and simultaneously enables an Internet bookstore to accomplish management objectives such as continuous growth and profit maximization.

The meanings that the study has, in relation with the behavioral resource distribution decision making of an internet bookstore, are as follows. First, the unified form of modeling is conducted after verifying partial knowledge, related to the decision making on purchase in the existing internet shopping malls so that viewing them from the overall perspective is possible. As seen from the previously analyzed outcomes, if investment on price reduction is expanded as for the strategic variable, securing visitors or actual consumers in the early stage of a internet bookstore, securing initial visitors or consumers may be possible, however, it will, after some point of time, rather bring the bad influences on the shopping environments of general/loyal consumers by affecting the purchase environment and the web surfing environment in a bad way due to the increase of a web server traffic. Even if the initial profitability of an internet bookstore increases through the variable, it will eventually worsen the profitability as time passes.

Furthermore, due to the increase in the number of buying customers, the complaints will be accumulated regarding delivery service or customer support service, possibly causing the potential consumers to stay away from the internet shopping mall or current consumers to give up their purchases. Therefore, the administrator of an internet bookstore must unify the partial knowledge, related to the purchase decision making on the internet, and utilize the investment strategies for each variable with the consideration on the overall picture from the systematic perspective. Secondly, the suggested methodology in the study makes the decision maker of a internet shopping mall learn and understand the behavioral mechanism of objective system. In other words, it shows that the alternatives for decision making related to the resources management are changing depending on the condition the internet based company is facing. Also, the most optimized alternative for making decision is suggested. Such influential elements as internet ads, promotional activities, and the price reduction are important, which can stimulate the purchase for new customers, whereas providing newer and richer contents and establishing faster and more accurate delivery service are needed for existing customers and loyal customers. Furthermore, it is mostly important to arrange the condition where customers can make transactions under a more convenient and more stable environment. The mutually important strategic variable for new customers or existing consumers is to build the web environment with more stability and faster speed, thus, from the perspective of an internet based company, making more investment on the hardware of the web service is necessary. In other words, it is essential to try eliminating various risk factors involved with the purchase before-hand, such as the environment and security where faster connection to the web server is possible. And it is another meaning of this study to prevent the potential errors of management before-hand, which are easy to be made, by controlling the values of important variables per each point of time or per each situation. Thirdly, the customer attraction effect of price reduction, which was used mostly by internet bookstores in their initial period of formation to compete with offline bookstores, and the effect of increase in profitability of an internet based bookstore are examined. As seen in the results from analysis, price reduction policy in the market of the internet bookstore has partial effects on securing customers at the initial stage or sales promotions; however, it eventually worsens the profit structure of the internet bookstore. From the perspective of internet based bookstores, securing customers may be important, but what is more important than that is to secure actual/loyal customers who can create profits for companies. It appears that price reduction policy, in some degree, has some effects on securing initial customers or attracting purchasing customers, whereas it does not have any effects on promoting the actual purchase, compared to the investment in the effect of price reduction. Therefore, the administrator of a internet bookstore has to arrange more convenient and safer environment for internet purchase by using the long term perspective oriented effect of attracting customers such as specializing the contents of the web, building a database, and strengthening the capability of more advanced web server rather than trying to boost up the increase in the number of customers through a short term oriented price reduction policy.

While conducting the study, the following are the potential research issues as to the limit of the study that have to be considered in the expanding step of the future upcoming study. First, it lacks in analysis of customer's behavior, conducting each step of searching and purchasing in different areas of online and offline. In other words, the case that searching products, related to the product purchase, is conducted online while actual purchase being done offline and the case that searching is done offline, while the purchase is done online are not applied in the model. Although online shopping has been a trendy thing due to the widespread environment of the internet recently, in some parts, customers still have separated categories of products each for online and offline. According to the study by Peterson et al., (1997), regarding the purchase possibility in internet shopping malls, it is likely that the purchase possibility is high when the product is cheap, to be purchased more frequently, and has less chance of being differentiated in the aspect of product specialization. It means that the 'low-involvement-products' – low risk products which are pretty much standardized with low price range – are to be purchased through online more likely, whereas 'high-involvement-products' – high risk products which are not standardized and are not in the low price range – are more likely to be purchased through offline still. Therefore, the issue regarding customers' shopping related behavioral interactions in between offline and online will have to be further researched. Furthermore, the study lacks in investigating on complex shopping mall (broad-line) and the mixed form of online and offline shopping mall. It uses the internet bookstore, which is the type of internet-only-specialized-shopping mall, that the study conducted its research on, however, it is assumable that outcomes may be different in the case of a rather complex form of shopping mall or a mixed type of online and offline shopping mall. Therefore, it is necessary to further study these different types of shopping malls. Thus, other variables, which are not applied in this study, will have to be applied as further researches are carried on.

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20

Pricing in Supply Chain under Vendor Managed Inventory

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1. Introduction

The successful implementation of supply chain management depends on many soft issues (strategic/behavioural) such as organizational resistance to change, inter-functional conflicts, joint production planning, profit sharing, team oriented performance measures, channel power shift, information sharing, real time communication, inventory and technical compatibility (Min & Zhou 2002). Many of the above issues in SCM are conceptually addressed and lot of scope exists for improving the performance of SC with good modelling. The soft issues of supply chain models can be dealt through proper information sharing, communication and coordination between the stages of supply chain. Vendor managed inventory (VMI) is a proven concept for successful collaborative and cooperative agreements in supply chain. While research has been slowly increasing in the area of vendor managed inventory, it has received very little attention in current operations literature. This chapter focuses on the soft issues of profit sharing and pricing under vendor managed inventory systems. Two vital parameters that govern the operation of a supply chain are: sales price at buyers market, and contract price between vendor and buyer. Sales price is significant in the sense that it determines the overall profit of the supply chain, referred here as channel profit. This chapter proposes five mathematical models under VMI environment for determination of optimal sales quantity for each buyer which maximizes the channel profit and subsequently to derive the sales and contract price from the optimal sales quantity.

2. Two-echelon supply chains

In the present internet / E-commerce arena, the stages in SC are less and the manufacturers access the customer requirement through retailers. Dell computers have reoriented its strategy by reducing it's down-stream stages and sells through its retail outlets in a particular region (Chopra, 2003). Procter and Gamble manages, monitors and replenishes its FMCG products in Wal-Mart stores (Clark & Croson, 1994). The success stories of these Giants have led the researchers to concentrate on two-echelon supply chain (Cachon & Zipkin, 1999). The two-echelon can be considered sequentially between any two of these stages such as suppliers, manufacturers, distributors, wholesalers, retailers, and end-customer. There are three types of environments addressed in two-echelon SC and they are:

i. **Single vendor-single buyer** (Banerjee, 1986; Goyal, 1997; Hill, 1997; Viswanathan, 1998; Bhattacharjee & Ramesh, 2000; Goyal & Nebebe, 2000; Hoque & Goyal, 2000; Dong & Xu, 2002; Lee & Chu, 2005),
ii. **Single vendor-multiple buyers** (Lu 1995; Gavirneni, 2001 and Yao & Chiou 2004) and
iii. **Multiple vendors - multiple buyers** (Cachon, 2001; Minner 2003; Sedarage *et al.*, 1999; Ganeshan, 1999).

The above three environments addressed by the numerous researchers were operating under independent mode with various objectives. Single vendor-single buyer is considered as an idealistic one in dealing with bottleneck cases and the remaining two cases represent the most practical situations. This chapter proposes five types of environments in two-echelon supply chain model operating under vendor managed inventory mode as given below (Nachiappan et al. 2006; Nachiappan & Jawahar 2007; Nachiappan et al. 2007; Nachiappan et al. 2007a). The parameters involved are explained at the end of the model description.

i. Single Vendor Single Buyer (SV_SB)

The single vendor single buyer as shown in figure1 is known as an idealistic case.

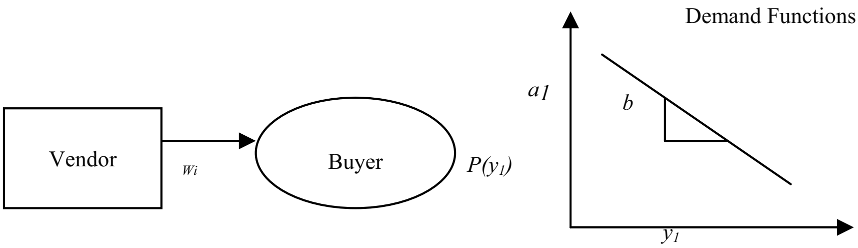

Figure 1 SV_SB Model

ii. Single Vendor Multiple Buyer's (SV_MB)

Single vendor multiple buyer's case is shown in figure 2. Few examples for this case cases are: Tamilnadu Cooperative milk producer's federation limited (AAVIN) Madurai, India (Single Vendor) selling its milk products to 423 commission agents (Multiple Buyers) in and around Madurai; Bharat Petroleum Corporation, Cochin, India (Single Vendor) distributing its petroleum products to 2500 sales points (Multiple Buyers) in southern part of India.

iii. Single Vendor Multiple Buyer's with Outsourcing (SV_MBO)

When the cumulative demand of all buyers goes up more than the vendor capacity, outsourcing is the option for the vendor to satisfy buyer's demand. Nowadays outsourcing is becoming part of regular activity in both manufacturing organizations and service providers.

Globalization pushes both of them into highly competitive environment. Outsourcing occurs because a firm may find it less profitable or not feasible to produce all required capabilities in-house. Outsourcing is an acceptable strategy to meet the excess demands than the limited capacity of the vendor. Outsourcing incorporated with SV_MB model, operating under VMI mode as shown in figure 3 is referred as Single Vendor Multiple Buyers with Outsourcing (SV_MBO)

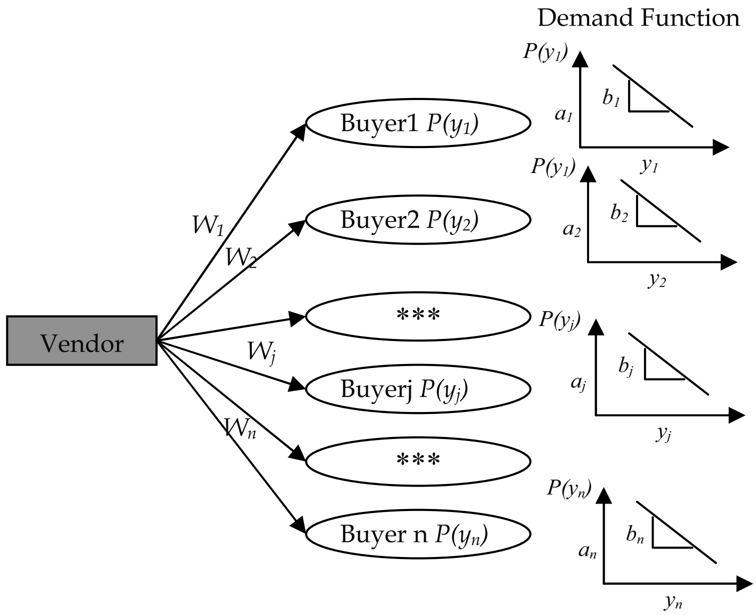

Figure 2. SV_MB model

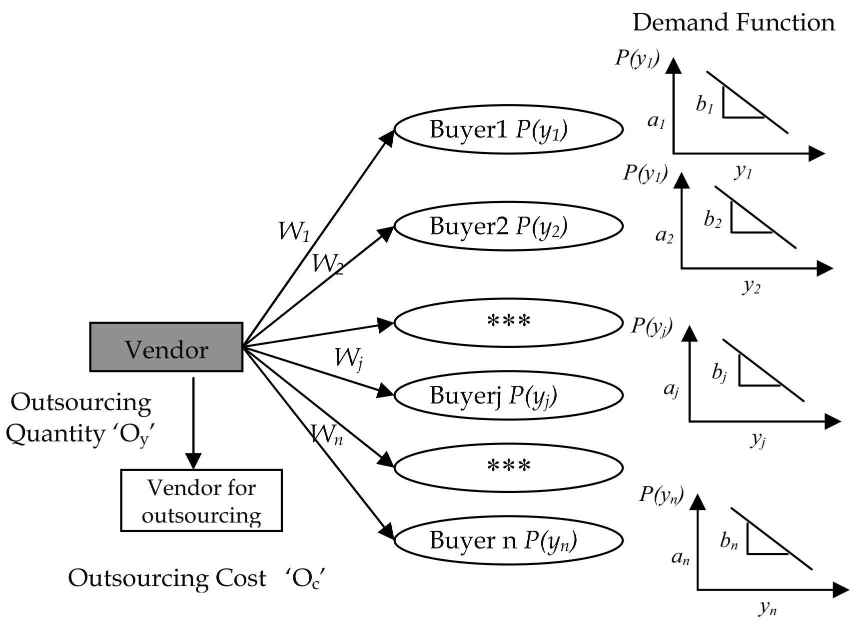

Figure 3. SV_MBO Model

iv. Multiple Vendors Multiple Buyers (MV_MB)

Few examples of multiple vendors multiple buyers as shown in figure 4 are as follows: Gold suppliers (Multiple Vendors) are selling gold through thousands of retailer's network (Multiple Buyers) and numerous grain suppliers (Multiple Vendors) supplying grains through thousands of retailers (Multiple Buyers).

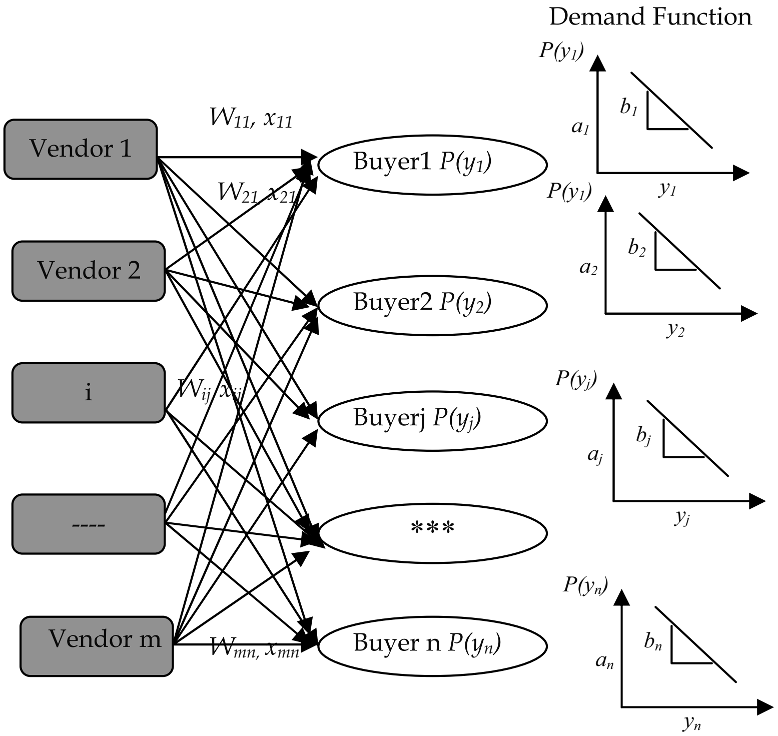

Figure 4. MV_MB model

v. Multiple Vendors Multiple Buyers with Outsourcing (MV_MBO)

Similar to SV_MBO whenever the cumulative demand of all buyers exceeds the capacity of all vendors, outsourcing is the only option for the vendors to satisfy the buyers demand. The MV_MB model with outsourcing (MV_MBO) is shown in figure 5.

Model Parameters

The demand pattern, sales quantity range at the buyers end and the importance of contract price between vendor(s) and buyer(s) are given below

Demand Pattern: The sales quantity of any product at a particular location is greatly influenced by its sales price'$P(y_j)$' (Waller *et. al.*, 2001). It depends on the factors such as necessity of the commodity (essential or occasional), purchasing power of the customers and nature of the product (perishable or storable). The general observation is that the higher sales price results low sales quantity and vice versa, provided the reputation and history of the company or brand value have no greater impact on the customers and/or there is at least one stiff customer (local or global) to control the sales price.

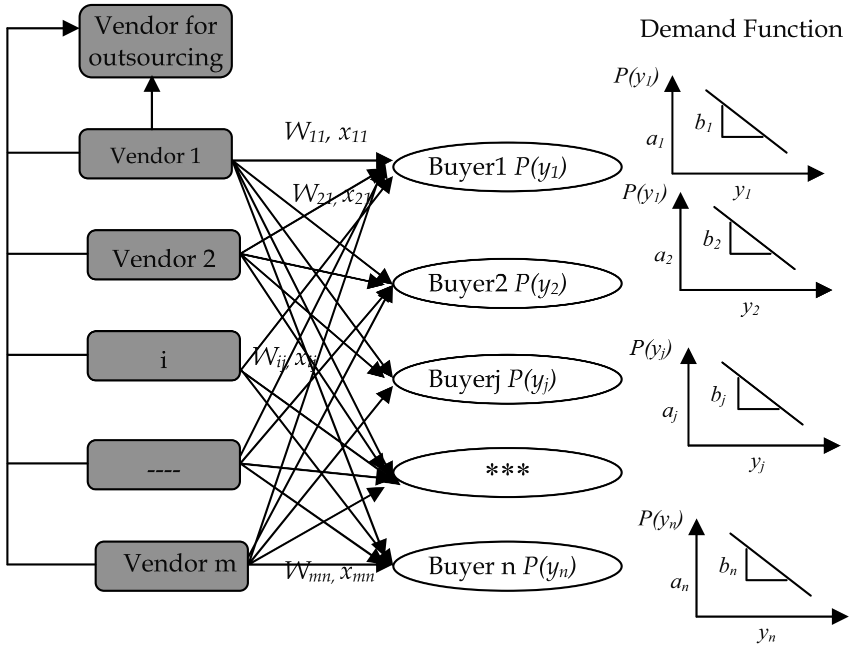

Figure 5. MV_MBO model

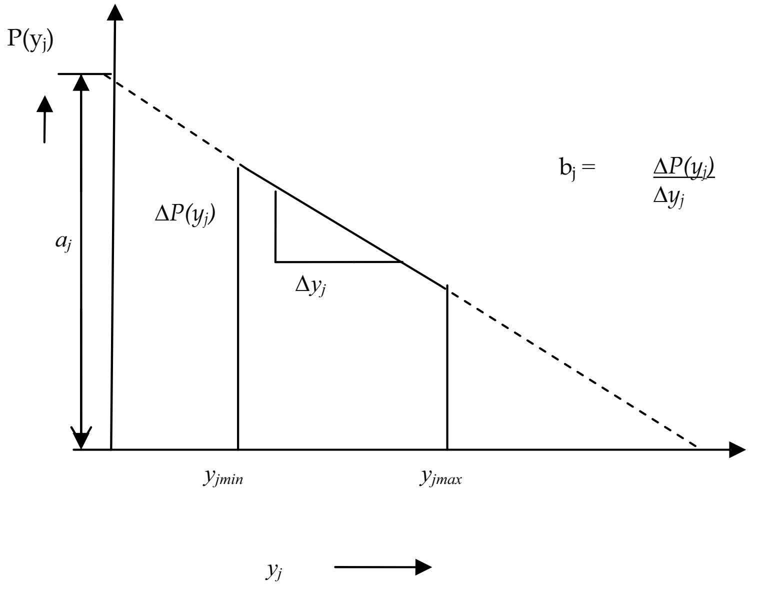

Figure 6. Relationship between sales price and sales quantity

Taking into account the above for consideration, the relationship between '$P(y_j)$' and 'y_j' may be assumed to behave linearly (Lau & Lau, 2003) and is given as:

$$P(y_j) = a_j - b_j y_j \tag{1}$$

Where, a_j and b_j are the intercept of '$P(y_j)$' axis and the slope of sales quantity /curve respectively in the sales price vs sales quantity graph shown in figure 6. This becomes the demand function for the buyer

Sales Quantity Range: Sales quantity lies between a specific range between y_{jmin} and y_{jmax} and the validity of the assumption of linear demand function holds very well within this range.

Contract Price: Contract Price (w_{ij}) is a price mutually agreed between i^{th} vendor and j^{th} buyer which decide the profits of both vendor and buyer and hence it is considered as vital. Usually it lies between sales price and cost of manufacturing. Nature of the product, demand and logistic cost play critically in the fixation of contract price. The commodities that have good reputation and high demand are usually fast moving and involve low risk (probability of loss). In these circumstances, the buyer accepts the contract price closer to sales price, even with meager margin on the reasons stated as: Loss due to obsolescence is negligible; Non availability of the commodity results in loss of customers that would definitely reduce the overall turnover of the outlet; Storage/Holding cost is normally low. However in an another scenario, where the product is new and demand is not yet stabilized, the contract price is expected to settle at a lower level, closer to cost of production. The possible reasons are: Outlets of the commodity take the task of promoting the new product; Cost of inventory is expected to be high. In such cases, ethical issues like cooperation, revenue and knowledge sharing are needed to compete with the existing commodity and consolidate its market. The above discussions point out that contract price is a variable, which is dependent on location, competitiveness of the products and production and operational costs between vendor and buyer. This shows that contract price play a vital role in the context of revenue sharing.

3. Vendor managed inventory

The soft issues of SC models can be dealt through proper information sharing, communication and coordination between the stages of SC. Examples of collaborative and cooperative agreements come in many forms and by many names, including Continuous Replenishment (CR), Vendor Managed Inventory (VMI), Collaborative Forecasting, Planning and Replenishment (CFPR) and Information Sharing Programs (ISP). The overall goal shared by all these programs is to reduce costs and to increase efficiency in the SC by sharing the information and/or by the transfer of decision rights (Mishra & Raghunathan, 2004; Fry, 2002; Ballou *et al.*, 2000; Hammond, 1990). VMI is a proven concept for successful collaborative and cooperative agreements in SC. The core concept of VMI has been that the supplier monitors the customers' demand and inventory and replenishes that inventory as needed with no action on the part of the customer (Dong & Xu, 2002 ; Disney & Towill, 2002). Waller *et al.* (2001) noted that the main advantages of VMI were reduced costs and increased customer service levels to one or both of the participating members. VMI, however, has received very little attention in current operations' literature, particularly operations texts, but it has been widely recognized by industry leaders, such as Wal-Mart and the Campbell soup company for creating a competitive advantage. Franchise organizations have also made use of VMI to provide a higher level of operating efficiency

(Williams, 2000). Cetinkaya & Lee (2000) noted that, with VMI, inventory carrying costs were generally reduced, as were stock out problems while the approach offered the ability to synchronise inventory and transportation decisions. VMI has differed from a fixed-order interval model or a fixed-order quantity model in that neither the time nor the quantity of replenishment was necessarily fixed. The supplier was responsible for managing the inventory at the customer's location, generally using information technology, and for sending the correct amount at the correct time (Burke, 1996; Parks & Popolillo, 1999). While research has been slowly increasing in the area of VMI, certain segments of business have appeared to be getting less attention than others (Latamore & Benton, 1999). The SC's of large retail and manufacturing organizations have been the foci of most of the research. Mabert & Venkataramanan (1998) pointed out that little work had been carried out in applying SCM techniques to service sectors. *Therefore this chapter concentrates on VMI systems for two-echelon models in the service sectors.*

3.1 Mathematical representation of vendor operations and costs

The relationship between two partners in any two-echelon supply chain model under VMI mode of operation with the various activities, mutual agreement, knowledge sharing and cooperation is shown in figure 7.

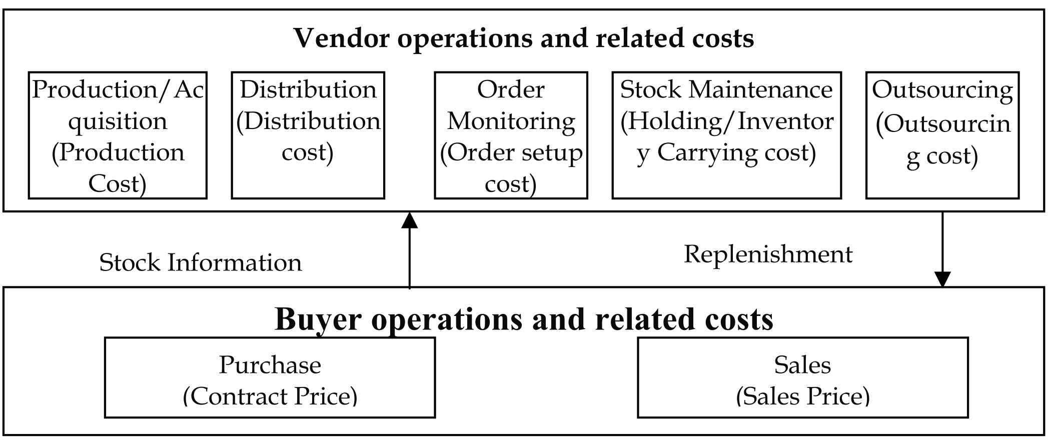

Figure 7. Operation mode of VMI systems with Outsourcing

3.1.1 Responsibility of the vendor

Vendor shares more responsibilities than buyer and acts as a leader. Vendor monitors, manages and replenishes inventory of buyer location (Achabal *et al.,* 2000, Disney & Towill, 2003). The costs associated with the above activities are: production cost, distribution cost and order setup cost stock maintenance cost and outsourcing cost if applicable.

Cost functions of the vendor

Production and distribution cost

Let 'δ_i' be the amount spent by a single vendor for producing a single unit. Then, the cost of production to meet the j^{th} customer becomes '$\delta_i y_j$'. Distribution cost is the product of flow and transportation resource cost. Flow cost consists of the direct mileage and carrier contract cost per unit form i^{th} vendor of the j^{th} buyer 'θ_{ij}'. The transportation resource cost is the indirect cost such as the mode of transport, human router cost and administrative costs and termed as 'γ_{ij}' per unit demand for the j^{th} buyer from i^{th} vendor (Dong and Xu, 2002). Therefore, the distribution cost = $(\theta_{ij}y_{ij})(\gamma_{ij}y_{ij})$. The distribution cost varies parabolically depending upon the increase in quantity and mode of transportation. Since in VMI mode, the vendor has to monitor inventory and to replenish products as and when required, there will be exponential variation in distribution cost depending upon the increase in quantity and mode of transportation.

$$PD_{ij} = \delta_i y_j + \gamma_{ij}\theta_{ij} y_j 2 \tag{2}$$

Order and stock maintenance cost

The vendor monitors the stock status and replenishes the stock. The buyer does not initiate orders. Therefore the order / setup cost per replenishment 'S_{ijVMI}' associated with continuously monitoring the stock status is assumed to be the sum of order/setup cost of the vendor 'S_{Si}' and the order/setup cost of the buyer 'S_{bj}' (Dong & Xu, 2002). Therefore cost involved to replenish the batches 'Q_{ij}' of demand of the j^{th} buyer 'y_j' is given as Order / setup cost for replenishment = $((S_{Si} + S_{bj})y_j/Q_{ij})$.

Inventory, whatever is the mode of operation, is held at both vendor and buyer locations H_{Si} and H_{bj} are the cost of holding one unit per unit time at the i^{th} vendor and the j^{th} buyer's location respectively. In order to replenish Q_{ij} to buyer 'j' the vendor 'i' accumulates this before delivery. Therefore the vendor 'i' holds an average inventory of $Q_{ij}/2$ to replenish buyer 'j' and VMI cost of holding inventory (H_{ijVMI}) becomes the sum of H_{Si} and H_{bj} (Dong & Xu, 2002). Therefore the stock maintenance cost is given as $(H_{Si}+H_{bj})\ Q_{ij}/2$.

Thus the order and stock maintenance cost OSM_{ij} of the vendor is the sum of the order setup cost and the average inventory holding cost and is as follows:

$$OSM_{ij} = (S_{Si} + S_{bj})y_j/Q_{ij} + (H_{Si}+H_{bj})\ Q_{ij}/2 \tag{3}$$

In this mode of operation the replenishment process takes place instantaneously, therefore to minimize the OSM_{ij}, Economic Order Quantity (EOQ_{ij}) for buyer is determined by equating the first differential of OSM_{ij} to zero.

$$d(OSM_{ij})/dQ_j = 0$$

$$EOQ_{ij} = [2(S_{Si}+S_{bj})y_j\ /\ (H_{Si}+H_{bj})]^{1/2} \tag{4}$$

Substituting EOQ_j for Q_j, in equation (3)

$$OSM_{ij} = [2(H_{Si}+H_{bj})(S_{Si}+S_{bj})y_j]^{1/2} \tag{5}$$

Outsourcing cost:

Whenever, the aggregate sales quantity $(\sum_{j=1}^{n} y_j)$ of all the buyers exceeds the capacity 'C' of the vendor, then the vendor has to outsource the extra quantities 'o_y' $(= \sum_{j=1}^{n} y_j - C)$. It is assumed that an additional cost incurred for vendor to outsource a unit is 'η' times of unit production cost 'δ'.

There fore outsourcing

$$o_c = \beta\eta\delta\,(\sum_{j=1}^{n} y_j\text{-C}) \tag{6}$$

Where,

$$\beta = 1,\ \text{if}\ (\sum_{j=1}^{n} y_j\text{-C}) > 0 \tag{7}$$

$$\beta = 0,\ \text{if}\ (\sum_{j=1}^{n} y_j\text{-C}) < 0 \tag{8}$$

In case of multiple buyers, the outsourcing cost is equally distributed to each buyer when calculating the vendor profit and contract prices for individual buyer *'j'* which is given as, For *'n'* number of buyers outsourcing cost

$$\text{'}o_{cj}\text{'} = \beta\eta\delta\,(\sum_{j=1}^{n} y_j\text{-C})/n \tag{9}$$

The profit of Vendor 'P_{sj}' when supplying the product to j^{th} buyer is the difference between revenue to the vendor and the total cost involved, which is represented as

$$P_{sj} = W_{ij}\,y_j - PD_{ij} - OSM_{ij} - o_{cj} \tag{10}$$

Therefore the total profit to the vendor P_s by supplying the products to all buyers is as follows:

$$P_s = \sum_{j=1}^{n} P_{sj} = \sum_{j=1}^{n} \{\, W_{ij}\,y_j - (\delta_i\, y_j + \gamma_{ij}\theta_{ij}\, y_j^2) - [(2(H_{i\,jVMI})(S_{ijVMI})y_j)^{1/2} - ((\beta\eta\delta(\sum_{j=1}^{n} y_j\text{-C}))/n)]\} \tag{11}$$

3.1.2 Buyer operation and costs

The buyer acts as an agent for the vendor and provides space to sell the products. Since the buyer deals with multiple products, maintenance costs are assumed to be negligible for a single product. Therefore the only cost associated with the buyers in VMI mode is the cost of purchase which depends on contract price. It is generally believed that acceptable (fair) pricing to the partners involved is an important factor for better relations in VMI and it requires acceptable contract price to be agreed that would satisfy both the vendor and the buyer (Grieger, 2003). The main focus of revenue sharing is to share the revenues/profits 'PR_{ij}' generated based on the assignments and responsibilities in order to avoid the conflict between SC partners (Maloni & Benton, 1997). This reveals that revenue sharing between vendor and buyer plays a vital role in fixing the contract price. Thus the profit of a buyer 'Pb_j' in VMI mode is the difference between sales revenue and the cost of purchase and is represented as:

$$Pb_j = P(y_j)y_j - W_{ij}\,y_j \tag{8}$$

Substituting $P(y_j)$ from equation 1 ,

$$Pb_j = (a_j - b_j y_j)\, y_j - W_{ij}\, y_j \tag{9}$$

For the known revenue share ratio *($PR_{ij} = Ps_j / Pb_j$)* between the vendor 'i' and buyer 'j' the contract price can be derived as:

$$W_{ij} = \{a_j y_j PR_j - b_j y_j^2 PR_j + \delta y_j + \gamma_j \theta_j y_j^2 + [(2(H_{jVMI})(S_{jVMI})\, y_j)^{1/2} - ((\beta\eta\delta(\sum_{j=1}^{n} y_j - C))/n)]\} \div [(1+PR_j) y_j] \tag{10}$$

4. Objective

The turnover and profit of an organisation depend on the price and demand of its products. The reasons for the non purchase of preferred commodities by customers are: 59% too expensive; 8% disliked appearance; 12% shelf life too short and 3 % inconsistent quality (Tronstad, 1995). Most of the models on pricing focus on profit generation at single level (Rajan *et al.*, 1992; Gallego & Vanryzin, 1994; Polatoglu, 1991; Desarbo *et al.*, 1987). Manufacturers fix price to the wholesaler which is known as supply price, considering manufacturing and distribution costs. Wholesaler offers a price to the retailer based on money turnover / commission. The retailer sells at a price depending upon market conditions. Hence pricing is an essential component of a product which makes customer more sensitive. Rather, trial and error method is often followed in organizations which involve finding out customer demand and other influential parameters such as market share, economic conditions, manufacturing capacity, nature of the product, inventory costs, cyclic fluctuations in cost and demand and rapid deterioration of product. Pricing mechanism differs with nature of the product (perishable, storable, seasonal, etc.,), government regulations (duties, licensing, etc.) and type of market (monopoly, oligopoly etc.) (Klastorin, 2004). The conventional trial and error pricing mechanism may not yield fruitful solution to SC scenario, in which all the entities need to work together in order to meet the global competition (i.e., between supply chains) in the market for long term (Casati *et al.,* 2001). Under the light of the stated issues, this chapter deals with the pricing mechanism in a SC models.

Two vital parameters that govern the operation of a SC are: sales price at buyers market and contract price between vendor and buyer. *Sales price* is significant in the sense that it determines the overall profit of the supply chain, referred here as channel profit. The existence of partnership relies on *contract price*. It is generally believed that pricing acceptable (fair) to the partners involved is an important factor for better relations in VMI and that it requires optimal sales and contract prices that would satisfy both vendor and buyer (Grieger, 2003). No partner would compromise on due share of profit. Besides, revenue sharing is the concept in which total channel profit should be allocated among SC participants in different profit ratios (Giannoccaro & Pontrandolfo, 2004). The main focus of revenue sharing is to share the revenues/profits generated based on the assignments and responsibilities in order to avoid the conflict between SC partners (Maloni & Benton, 1997). Min & Zhou (2002) pointed out that profit sharing is believed as one of the major behavioural (soft) issues in strengthening the relationship between partners of SC to improve the performance. Gjerdrum *et al.* (2002) pointed out that fair optimized profit distribution between the partners would lead to better relationship and only this kind of distribution can be the genuine deal

In general the contract price dictated by the vendor will be higher for most acceptable (fair) product for which demand is high, since there is low risk involved to the buyers and therefore the revenue share to the vendor will be normally high or equal. On the other hand, for the newly launched product, contract price dictated by the vendor will be meager, since the buyer takes the responsibility of promoting the sale of the product and therefore the revenue share to the buyer will be very high. This reveals that the contract price plays a vital role in VMI context of revenue sharing. Moreover, fixation of contract price for the different revenue ratio is a tedious process, which leads to conflicts between partners if it is not properly adopted (Gjerdrum *et al.*, 2002). It is evident from the above discussion that the contract and sales prices, which determine the profits of buyer, vendor and channel (sum of buyer and vendor profit), are the key parameters for the successful adaptation of VMI..

Members of SC addressed as partners, promote and adopt strategies to minimize cost or maximize turnover. The traditional objective of the supply chain is to minimize total supply chain cost to meet the given demand. Researchers argue that total cost minimization is an inappropriate and timid objective for the firm to pursue when it analyses its strategic and tactical supply chain plans (Shapiro, 2001; Gjerdrum *et al.*, 2002). Instead maximization of net revenue could be considered as appropriate objective to supply chain. In the literature on Supply Chain Management (SCM), the net revenue is addressed as channel profit P_c'. Therefore determination of optimal sales quantity (y_{jopt}) for each buyer j, which maximizes the P_c' becomes the objective of this chapter. The sales price $P(y_{jopt})$ and contract price W_{jopt} could be subsequently derived with the 'y_{jopt}' obtained through various heuristics. *Concerning the above, this chapter determine the optimal prices (contract and sales prices) for maximum channel profit in SC models operating under VMI mode of operation.*

The objective of VMI systems, in general are: inventory reduction and increased responsiveness. Both of them are aimed to increase the channel profit (ethical optimisation). Besides, a fair revenue share between vendor and buyer would strengthen the partnership in SC model. These two factors (channel profit and revenue share) are considered as the objectives of the model. The problem is stated as:

Determination of

i. optimal combination of sales quantity' y_{jopt}' (for $\forall$j) for maximum channel profit 'Pc' of two echelon supply chain operating in VMI mode of operation and
ii. Operating parameters such sales prices 'P(yj)' (for $\forall$j) corresponding to 'y_{jopt}' and acceptable contract prices Wj (for$\forall$j) under different revenue shares 'PRj'(for $\forall$j) and outsourcing quantity 'oy' for vendor (if applicable),given the following:
   - production cost per unit 'δ_i'(for $\forall$i)
   - flow cost per unit 'θ_{ij}' (for $\forall$i, for$\forall$j)
   - intercept 'a_j' (for $\forall$j) of demand function
   - cost slope 'b_j' (for $\forall$j) of demand function
   - order / setup cost of vendor 'S_{si}'(for $\forall$i) and buyer 'H_{bj}' (for $\forall$j)
   - holding cost of vendor 'H_{si}' (for $\forall$i)and buyer 'H_{bj}' (for $\forall$j)
   - capacity of the vendor 'C_i'(for $\forall$i)
   - Outsourcing cost constant 'η'
   - sales quantity range y_{jmin} and y_{jmax} (for $\forall$j) and

- revenue share ratio ‘PR_{ij}’(for ∀I ,for ∀j) between vendor and buyer.

4.1 Mathematical model for SV_SB

The mathematical model for SV_SB is given below

4.1.1 Optimal sales quantity

Maximize

$$P_c = \{Wy - (\delta\, y + \gamma\, \theta\, y^2) - [(2(H_{VMI})(S_{VMI})y)^{½}]\} \tag{11}$$

Subject to:

$$y_{min} \leq y \leq y_{max} \text{ (Buyer sales quantity constraints)} \tag{12}$$

$$y_{min} \leq C \leq y_{max} \quad \text{(Vendor capacity constraints)} \tag{13}$$

$$y_j \quad \geq 0 \quad \text{(Non-negative Constraint \& Integer)} \tag{14}$$

The solution to the above problem provides the optimal sales quantity ‘y_{opt}’

4.1.2 Optimal sales price

Optimal sales price is calculated by using equation (1)

$$P\ (y_{opt}) = a - b_j y_{opt}\ . \tag{15}$$

4.1.3 Acceptable contract price

The acceptable contract price ‘W_{opt}’ is arrived at by substituting the optimal sales quantity ‘y_{opt}’ in the equation

$$W_{opt} = \frac{ay_{opt}PR - b\, y^2 PR \ + \delta y_{opt} + \gamma\theta \ \ y_{opt}{}^2 + (2(H_{VMI})(S_{VMI})y_{opt}\,]^{1/2}}{(1+PR)\ y_{opt}} \tag{16}$$

4.2 Mathematical model for SV_MB

The mathematical model for SV_MB is given below

4.2.1 Optimal sales quantity

Maximize

$$P_c = \sum_{j=1}^{n} \{a_{\,j}\, y_j - b_j y_j^2 - \delta y_j - \gamma_j \theta_j\, y_j^2 - [2(H_{jVMIj})\,(S_{jVMI})\, y_j\,]^{1/2}\} \tag{17}$$

Subject to:

$$y_{jmin} \leq y_j \leq y_{jmax} \quad (for\ \forall j) \text{ (Buyer sales quantity constraints)} \tag{18}$$

$$\sum_{j=1}^{n} y_{jmin} \le C \le \sum_{j=1}^{n} y_{j\,max} \quad \text{(Vendor capacity constraints)} \tag{19}$$

$$y_j \quad \ge 0 \quad \text{(Non-negative Constraint \& Integer)} \tag{20}$$

The solution to the above problem provides optimal sales quantity 'y_{jopt}' *(for* $\forall j$*)*

4.2.2 Optimal sales price

The optimal sales price ($P(y_{jopt})$) is derived by substituting the optimal sales quantity (y_{jopt}) in equation (1) as furnished below.

$$P(y_{jopt}) = a_j - b_j y_{jopt} \tag{21}$$

4.2.3 Acceptable contract price

The acceptable contract price 'W_{jopt}' is derived by substituting the optimal sales quantity 'y_{jopt}' in the equation (10).

$$W_{j_{opt}} = \frac{a_j y_{jopt} PR_j - b_j\, y_{jopt}^{\,2} PR_j + \delta y_{jopt} + \gamma_j\, \theta_j\, y_{jopt}^{\,2} + (2(H_{iVMI})(S_{iVMI}) y_{jopt}\,)^{1/2}}{(1 + PR_j)\; y_{jopt}} \tag{22}$$

4.3 Mathematical model for SV_MBO

The mathematical model for SV_MBO is given below

4.3.1 Optimal sales quantity

$$\text{Max } Pc = \sum_{j=1}^{n} \{a_j y_j - b_j y_j^2 - \delta y_j - \gamma_j \theta_j y_j^2 - [(2(H_{jVMI})(S_{jVMI}) y_j)^{1/2} - ((\beta\eta\delta(\sum_{j=1}^{n} y_j - C))/n)]\} \tag{23}$$

Subject to

$$y_{jmin} \le y_j \le y_{jmax} \quad (\forall j) \text{ (Buyer demand constraints)} \tag{24}$$

$$y_j \quad \ge 0 \quad \text{(Non-negative Constraint \& Integer)} \tag{25}$$

The solution to the above problem provides the optimal combination of sales quantities 'y_{jopt}' ($\forall j$).

4.3.2 Optimal outsourcing quantity

Optimal outsourcing quantity is difference between sums of all buyers' optimal sales quantity and the capacity of the vendor which is given as,

$$oy_{opt} = \sum_{j=1}^{n} \{ y_{jopt}\} - C \quad \text{if} \quad \beta = 1 \tag{26}$$

$$= 0 \qquad \text{if} \qquad \beta = 0 \tag{26a}$$

4.3.3 Optimal sales price

Optimal sales price is calculated by using equation (1)

$$P\,(y_{jopt}) = a_j - b_j y_{jopt}\ (\forall j). \tag{27}$$

4.3.4 Acceptable contract price

The acceptable contract price W_{jopt}' is derived by substituting the optimal sales quantity 'y_{jopt}' and optimal outsourcing quantity 'o_{yopt}' in the equation 10.

$$\begin{aligned} W_{jopt} &= \{a_j y_{jopt} PR_j - b_j\, y_{jopt}{}^2 PR_j + \delta y_{jopt} + \gamma_j \theta_j y_{jopt}{}^2 + \\ &+ [(2(H_{jVMI})\,(S_{jVMI})\, y_{jopt})^{½} - ((ß\,\eta\delta(\sum_{j=1}^{n} y_{j\,opt} - C))/n)]\} \div [(1+PR_j) * y_{jopt}] \end{aligned} \tag{28}$$

4.4 Mathematical model for MV_MB

Sales quantity of the j^{th} buyer $y_j = \sum_{i=1}^{m} x_{ij}$, where x_{ij} is the transaction quantity between i^{th} vendor and j^{th} buyer

4.4.1 Optimal transaction quantity

Maximize

$$P_c = \sum_{j=1}^{n} \{a_j \sum_{i=1}^{m} x_{ij} - b_j (\sum_{i=1}^{m} x_{ij})^2\} - \sum_{i=1}^{m} \sum_{j=1}^{n} \{\delta_i x_{ij} + \gamma_j \theta_{ij} x_{ij}{}^2 + [2(H_{ijVMI})(S_{ijVMI}) x_{ij}]^{1/2}\} \tag{29}$$

Subject to:

$$y_{jmin} \le y_j \le y_{jmax} \quad \text{(for } \forall j\text{)(Buyer sales constraints)} \tag{30}$$

$$\sum_{j=1}^{n} y_{jmin} \le C_i \le \sum_{j=1}^{n} y_{j\,max} \ (for\ \forall j) \text{ (Vendor capacity constraints)} \tag{31}$$

$$y_j \ge 0 \text{ (Non-negative Constraint \& Integer)} \tag{32}$$

The solution to the above problem provides optimal transaction quantity 'x_{ijopt}' *(for* $\forall i, \forall j$*)*

4.4.2 Optimal sales price

The optimal sales price '$P(y_{jopt})$' is derived by substituting the optimal transaction quantity 'x_{ijopt}' in equation (1) as furnished below. Optimal sales quantity of the j^{th} buyer

$$y_{jopt} = \sum_{i=1}^{m} x_{ijopt}$$

$$P(y_{jopt}) = a_j - b_j y_{jopt} \tag{33}$$

4.4.3 Acceptable contract price

The acceptable contract price 'W_{ijopt}' is derived by substituting the optimal transaction quantity 'x_{ijopt}' in the equation (10)

$$W_{ijopt} = \frac{a_j x_{ijopt} PR_{ij} - b_j x_{ijopt}^2 PR_{ij} + \delta_i x_{ijopt} + \gamma_j \theta_{ij} x_{ijopt}^2 + (2(H_{ijVMI})(S_{ijVMI}) x_{ijopt})^{1/2}}{(1 + PR_{ij})\, x_{ijopt}} \tag{34}$$

4.5 Mathematical model for MV_MBO

4.5.1 Optimal transaction quantity

$$\text{Maximize } P_c = \sum_{j=1}^{n} \{a_j \sum_{i=1}^{m} (x_{ij} + Ox_{ij}) - b_j (\sum_{i=1}^{m} (x_{ij} + Ox_{ij})^2\} - \sum_{i=1}^{m} \sum_{j=1}^{n} \{ \delta_i (x_{ij} + Ox_{ij}) + \gamma_{ij} \theta_{ij}$$

$$(x_{ij} + Ox_{ij})^2 + [2(H_{ijVMI})(S_{ijVMI})\, x_{ij}]^{1/2} + (\lambda_i(\delta_i Ox_{ij} + \gamma_{ij}\, \theta_{ij} Ox_{ij}^2))\} \tag{35}$$

Subject to:

$$\sum_{i=1}^{m} (x_{ijmin} + Ox_{ijmin}) \le \sum_{i=1}^{m} (x_{ij} + Ox_{ij}) \le \sum_{i=1}^{m} (x_{ijmax} + Ox_{ijmax})$$

$$(\text{for } \forall j) \quad \text{(Buyer sales constraints)} \tag{36}$$

$$\sum_{i=1}^{m} (x_{ij} + Ox_{ij}) \ge 0 \text{ (Non- negative Constraint \& Integer)} \tag{37}$$

The solution to the above problem provides optimal transaction quantity 'x_{ijopt}' (for $\forall i$, $\forall j$)

4.5.2 Optimal outsourcing transaction quantity

The optimal outsourcing transaction quantity is derived as follows:

$$Ox_{ijopt} = \beta_{ij}(y_j - \sum_{i=1}^{m} x_{ijopt}); \tag{38}$$

where,

For every buyer 'j' β_{ij} =1; if the profit ratio with vendor 'i' is lowest; otherwise β_{ij} = 0;

4.5.3 Optimal sales price

The optimal sales price ‘$P(y_{jopt})$’ is derived by substituting ‘x_{ijopt}’ and ‘Ox_{ijopt}’ in equation (1) as furnished below.
Optimal sales quantity of the j^{th} buyer

$$y_{jopt} = \sum_{i=1}^{m} (X_{ijopt} + Ox_{ijopt})$$

$$P(y_{jopt}) = a_j - b_j y_{jopt} \ (\text{for } \forall j) \tag{39}$$

4.5.4 Acceptable contract price

The acceptable contract price ‘W_{ijopt}’ is derived by substituting the optimal transaction quantity ‘x_{ijopt}’ and Outsourcing transaction quantity ‘Ox_{ijopt}’ in the equation 10.

$$W_{ijopt} = \frac{a_j(x_{ij_{opt}} + Ox_{ijopt})PR_{ij} - b_j\,(x_{ijopt} + Ox_{ijopt})^2 PR_{ij} + \delta_i (x_{ijopt} + Ox_{ijopt}) +}{(1+PR_{ij})\,(x_{ijopt} + Ox_{ijopt})}$$

$$\frac{+\gamma_{ij}\theta_{ij}\,(x_{ijopt} + Ox_{ijopt})^2 + (2(H_{ijVMI})(S_{ijVMI})x_{ijopt}\,]^{1/2} + \lambda_i (\delta_i Ox_{ijopt} + \gamma_{ij}\theta_{ij} Ox_{ijopt}{}^2)}{(1+PR_{ij})\,(x_{ijopt} + Ox_{ijopt})} \tag{40}$$

5. Heuristics

Many well-known algorithmic advances in optimization have been made, but it turns out that most of them have not had the expected impact on the decisions for designing and optimizing supply chain related problems (Shapiro, 2001). For example, some optimization techniques are of little use because they are not well suited to solve complex real logistics problems in the short time, needed to make decisions. Also some techniques are highly problem-dependent and need high expertise. All the constraints of the problem may not be amenable to the mathematical articulation without such an articulation optimization may not be possible leaving the decision maker with no choice but to resort to his own experience. This adds difficulties in the implementations of optimization algorithms in the DSS which contradict the tendency to fast implementation in a rapid changing world. Alternatively for many of the problems, since the cost to find an optimal solution is so high, heuristic problem solving would suffice. Therefore, on the one hand there is the need for sophisticated logistics Decision Support System (DSS) to enable the organizations to respond quickly to new issues and problems faced on the SCM, and on the other hand there are advances in the area of heuristics that can provide an effective response to complex problems. This provides a fertile ground for applications of these techniques to SCM and subsequently of the development of computer based systems to help logistics decisions. Well-designed heuristics packages can maintain their advantage over optimization packages in terms of computer resources required, a consideration unlikely to diminish in importance so long as the size and complexity of the models arising in practice continue to increase. This is true for many areas in the firm, but especially to SCM related problems.

A heuristic algorithm (often shortened to heuristic) is a solution method that does not guarantee an optimal solution, but, in general, has a good level of performance in terms of solution quality and convergence. To develop a heuristic for a particular problem, some problem-specific characteristics must be defined. The problem-specific may include the definition of a feasible solution, the neighbourhood of a solution, rules for changing solutions, and rules for setting certain parameters during the course of execution (Corne *et al.*,1999; Glover & Gkochenberger, 2001). In fact, some of the most popular commercial packages use heuristic methods or rules of thumb. Heuristic may be constructive (producing a single solution) or local search (starting from one or given random solutions and moving iteratively to other nearby solutions) or a combination (constructing one or more solutions and using them to start a local search).

The area of heuristic techniques has been the object of intensive studies in the last decades. Recent advances in heuristic technique include meta-heuristics, which gained widespread applications along with the computational power of the computer technology. A meta-heuristic is a framework for producing heuristics, such as Simulated Annealing (SAA), Genetic Algorithm (GA), Tabu Search (TS), Particle Swarm Optimisation (PSO), Ant Colony Optimisation (ACO), etc. (Yokota *et al.*, 1996; Costa & Oliveira 2001; Wu, 2001). Meta-heuristics have many desirable features for becoming an excellent method: in general they are simple, easy to implement, robust and have been proven highly effective to solve hard problems. Even in their most simpler and basic implementation, the meta-heuristics have been able to effectively solve very hard and complex problems. There are several aspects which are worth enough to be mentioned. The most important one is the meta-heuristics modular nature that leads to short development times and updates, given a clear advantage over other techniques for industrial applications.

The other important aspect is that the amount of data involved in any optimization model for an integrated supply chain problem can be overwhelming. The complexity of the models for the SCM and the incapacity for solving in real time some of them by the traditional techniques force the use of the obvious techniques to reduce this complex issue by data aggregation (Simchi-Levi *et al.*, 2000). Therefore, instead of aggregating data to be able to obtain a simple and solvable model, but which will not represent well the reality, researchers should consider the complex model by using an approximation algorithm. The scenario-based approaches can incorporate a meta-heuristic to obtain the best possible decision within a scenario. The combination of best characteristics of human decision-making and computerised model and algorithmic based systems into interactive and graphical design frameworks have proven to be very effective in SCM, since many supply chain problems are new, subject to rapid changes and moreover, there is no clear understanding of all of the issues involved.

Rutenbar (1989) pointed out that simple heuristics is not capable of solving the hard problems with either numerous, contradictory constraints, or complex, baroque cost functions with respect to solution quality and execution time whereas meta heuristics such as GA and SAA are most suitable. SAA and GA are widely used for combinatorial optimization problems in different domains such as location, packing, partitioning and scheduling etc. SAA is a technique for combinatorial optimization problems, such as minimizing functions of very many variables. Because many real-world design problems can be cast in the form of such optimization problems, there is intense interest in general techniques for their solution. SAA is one such technique of rather recent vintage with an unusual pedigree: it is motivated by an analogy to the statistical mechanics of annealing in solids. GA makes no assumptions about the function to be optimized. All that a GA requires is a performance measure, some form of problem representation, and operators that generate new population members. This general approach has been applied to many difficult and novel optimization problems. GA's strength is its robustness, wide domain of applicability and global search capability. This modular aspect is especially important in implementing a DSS in a firm and the rapid changes that occur in the area of SCM. Lourenço (2005) pointed out that meta-heuristics, when incorporated to a DSS for SCM, can contribute significantly to the decision process, especially taking into consideration the increased complexity of the logistics problems previously presented. DSS, based on meta-heuristics, are not currently widespread, but it appears to be growing as a potential technique to solve hard problems as the one related with SCM. Taking into the above concerns, this section proposes decision support heuristics as given below in the table 1 for two echelon VMI systems considering the soft issues such as revenue sharing, pricing, real time communication, and determines the parameters such sales quantity, sales price and contract price between vendors and buyers for all two echelon environments.

S.No	Environment	Proposed heuristics
1	SV_SB	Iterative heuristic
2	SV_MBO	SAA based heuristic
3	MV_MBO	GA based heuristic

Table 1 Proposed heuristics

5.1. Iterative heuristics for SV_SB problem

Gjerdrum *et al.* (2002) addressed a method to fix fair transfer (contract) price in two enterprises SC and proposed an approach by applying the Nash bargaining principle for finding optimal multi–partner profit levels subject to given minimum echelon profit requirement. Fixation of contract price for the different revenue ratio is a tedious process, which leads to conflicts between partners, if it is not properly adopted in VMI system. Dong & Xu (2002) represented cost functions of VMI in partial differential equation and proposed a methodology to determine optimal sales quantity without giving due consideration to contract price under different revenue shares and highlighted the benefits of VMI than that of traditional mode of operation. In order to mitigate the above limitation, a new methodology is required to determine the contract prices for known revenue shares between vendor and buyer with the objective of maximizing the channel profit in two-echelon SC operating under VMI mode. The procedure should be simple and it can be easily adapted in real time by SC managers (Achabal *et. al.*, 2000). On this concern, this chapter proposes an iterative heuristic to find optimal contract and sales prices to operate under VMI mode for the problem described in section 4.1. Though the iterative approach involves large computations, present day computers can solve them within the reasonable time. Besides this, the time factor is not much crucial to this type of offline problems.

The proposed iterative heuristic involves the following two modules:

- Module 1: Determination of fair contract price (W) for various demands (y) or Sales prices $(P(y))$ on the assumption that they operate independently (i.e in Non VMI mode) with fair rewards or acceptable revenue shares.
- Module 2: Selection of optimal contract price (W_{opt}) based on the channel profits in VMI mode from various acceptable contract price (W) obtained in module 1.

Figure 8 illustrates the mechanism of the proposed iterative heuristic.

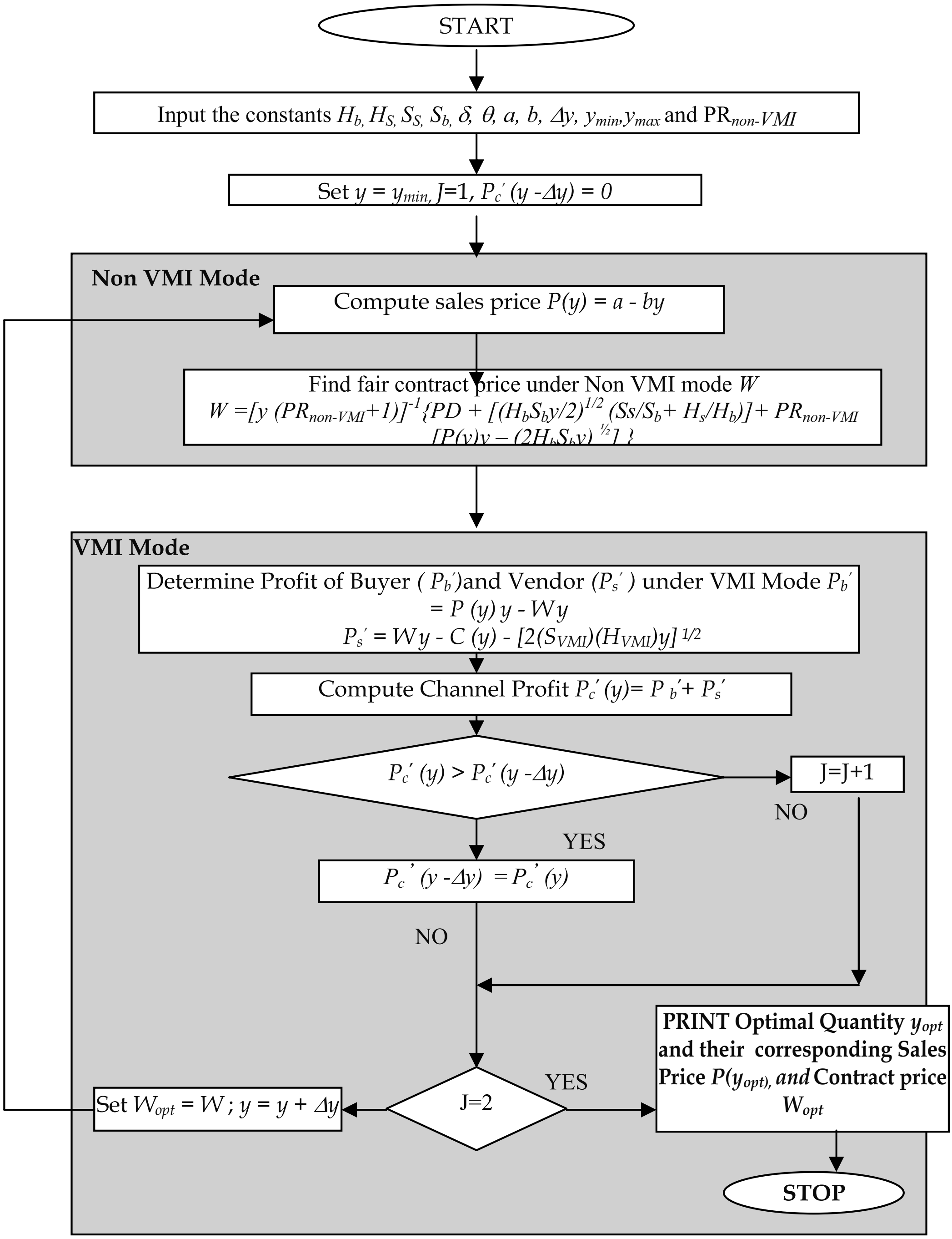

Figure 8. Iterative procedure of the proposed heuristic

5.2 SAA Based heuristics for SV_MBO

Simulated annealing is also an intriguing technique for optimizing functions of many variables (Kirkpatrick et al., 1983). It is a heuristic strategy that provides a means for optimization of MINP problems those for which an exponentially increasing number of steps are required to generate an exact answer (Eglese, 1990). Simulated annealing is based on an analogy to the cooling of heated metals. Ponnambalam *et al.* (1999) states that the algorithm based on SAA, is a generalization of the well-known iterative improvement approach to combinatorial optimization problems. A generic procedure of SAA is given below in figure 9. The various steps involved in the proposed algorithm are explained below.

5.2.1 Input module

Table 2 and Table 3 serve as the input data sets to SV_MB problem. They are given as input in this module.

Parameters	Buyer						
	1	2	3	….	j	….	n
Holding cost	H_{b1}	H_{b2}	H_{b3}	….	H_{bj}	….	H_{bn}
Order / Setup Cost	S_{b1}	S_{b2}	S_{b3}	….	S_{bj}	….	S_{bn}
Intercept	a_1	a_2	a_3	….	a_j	….	a_n
Cost slope	b_1	b_2	b_3	….	b_j	….	b_n
Minimum sales quantity	y_{1min}	y_{2min}	y_{3min}	….	y_{jmin}	….	y_{nmin}
Maximum sales quantity	y_{1max}	y_{2max}	y_{3max}		y_{jmax}	….	y_{nmax}
Revenue Share Ratio	PR_1	PR_2	PR_3	….	PR_j	….	PR_n
Flow cost per unit	θ_1	θ_2	θ_3	….	θ_j	….	θ_n

Table 2. Buyer related data

Holding cost	Order / Setup Cost	Capacity	Production Cost per unit.	Outsourcing cost constant
H_S	S_S	C	δ	η

Table 3. Vendor related data

5.2.2 Initialization module

Choose an initial temperature, *T*. The value of *T* is decided based upon the number of iterations to be performed. Here value of T is taken as 450 (Eglese, 1990). An initial set of sales quantity of all buyers is generated randomly with binary representation. A set of 9 digit binary numbers addresses one buyer. Each seed solution comprising of 'n' buyers is decoded to provide the feasible sales quantity 'y_j' in integers by interpolating the seed information of the binary form with the following guidelines: Zero in all the nine digits would correspond to y_{jmin} (i.e. 000000000 $\Rightarrow$ y_{jmin}) and 'one' in all the nine digits would correspond to y_{jmax} (i.e. 111111111 $\Rightarrow$ y_{jmax}). The binary type representation and the physical meaning are as shown in figure 10.

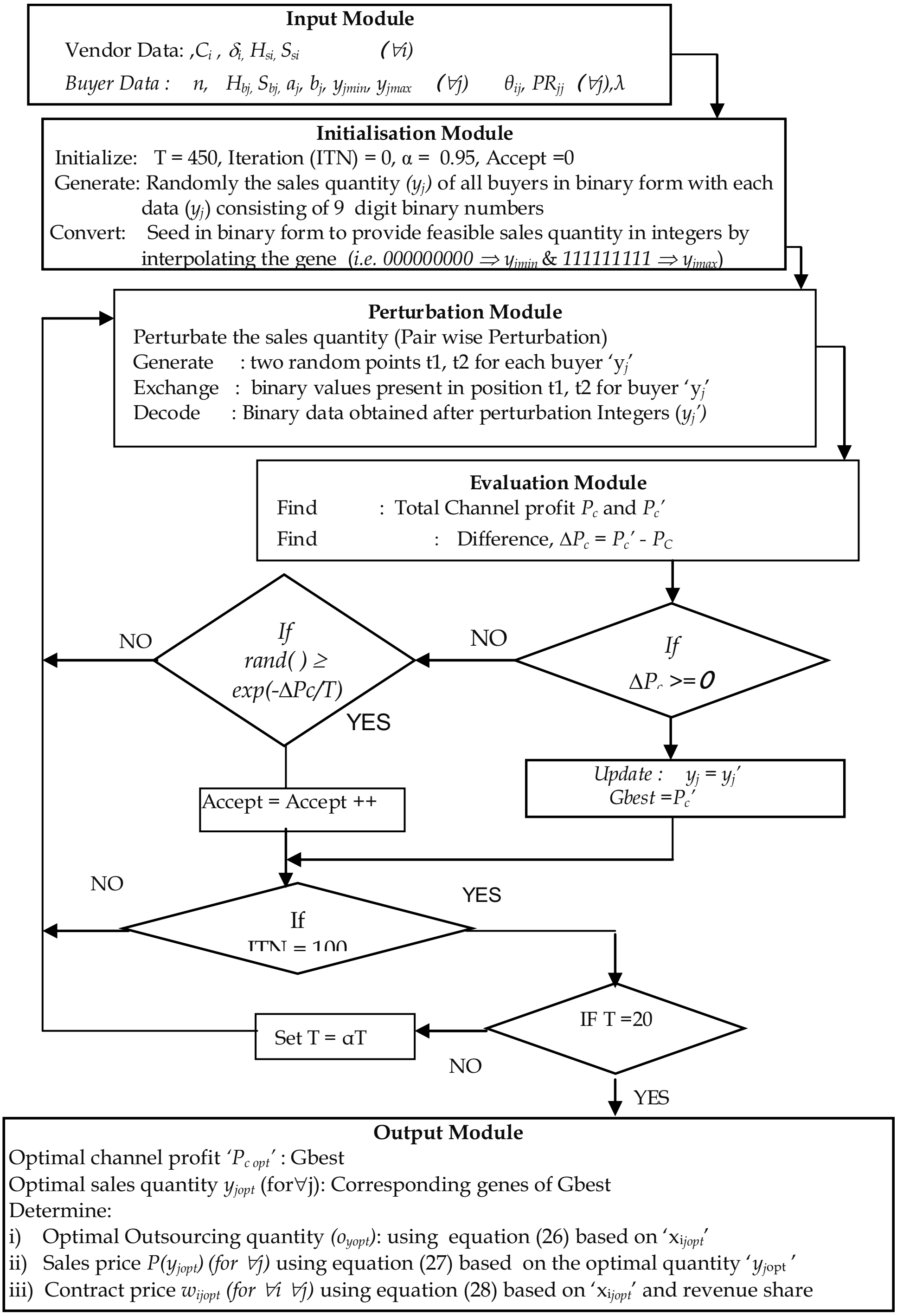

Figure 9. Flow chart representation of Simulated Annealing Algorithm process

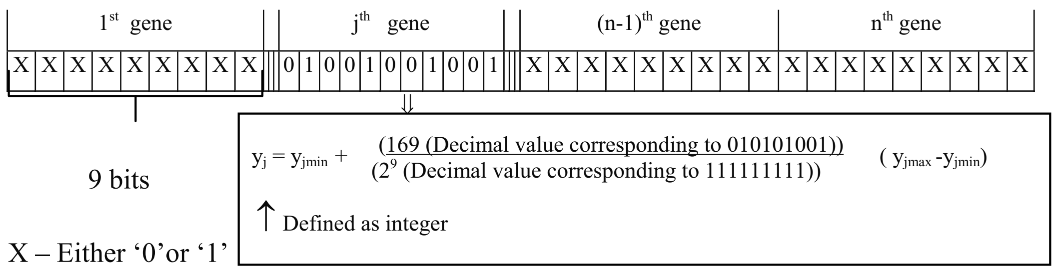

Figure 10. Binary representation and meaning

5.2.3 Perturbation module

Generate a feasible neighbour y_j' in the neighbourhood region of y_j by using perturbation mechanism. Pair wise exchange perturbation scheme is used. Two points are randomly generated for all buyers and the binary digits corresponding to the two points are exchanged to obtain the new seed. Then they are decoded as above to obtain the feasible sales quantity y_j' in integers.

5.2.4 Evaluation module

In this module, the sales quantities of all buyers are decoded as above to obtain the feasible sales quantity (y_j') in integers and the total channel profit are determined based on the following steps.

Determination of total channel profit:

The total channel profit (P_c) & (P_c') is determined for the sales quantity y_j and y_j' respectively. Then the differences between the two channel profits are determined.

$$\Delta Pc = Pc' - Pc \tag{41}$$

5.2.5 Update module

If the difference $\Delta P_c >= 0$, accept the neighbour y_j' as seed, assign (P_c') as Gbest else accept the inferior neighbour as seed with probability 'p'. i.e., rand ( ) ≤ exp ($-\Delta P_c$ / T).

5.2.6 Termination module

Termination criterion is first checked to know whether the pre-determined number of iterations is completed. If it is not completed, it goes to perturbation module otherwise the initial temperature is multiplied by factor α to obtain the new temperature, and proceeds to next step. Here value of α=0.95 (Ponnambalam *et al.*, 1999). A check is considered to identify whether the value of temperature falls below a predetermined value. If the value falls below then proceed to output module otherwise go to perturbation module.

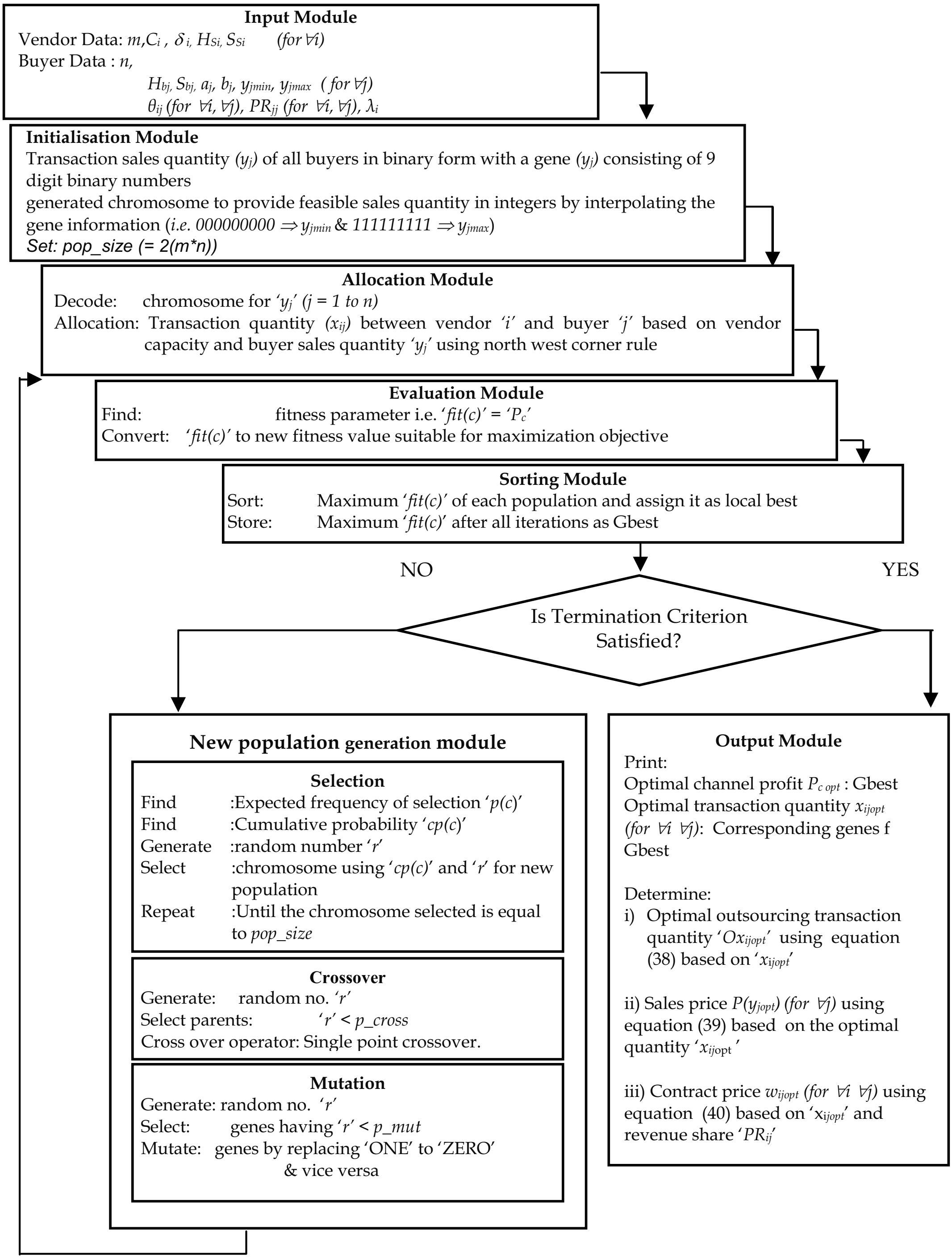

Figure 11. Structure of proposed GA based heuristics

5.2.7 Output module

After completion of all iterations, the Gbest fitness parameter sorted out is considered as the optimal channel profit P_{copt} and its corresponding y_j *(for* $\forall j$*)* becomes sales quantity of all the buyers y_{jopt} *(for* $\forall j$*)*. Optimal outsourcing quantity is determined using equation 26. Next, the optimal sales price $P(y_{jopt})$ *(for* $\forall j$*)* and optimal contract price W_{jopt} *(for* $\forall j$*)* corresponding to the optimal quantity y_{jopt} determined using the equations 27 and 28 respectively. Complete output obtained is shown in Table 4 for the optimal channel profit P_{copt}.

Operating Parameters	Buyer 1	Buyer 2	Buyer 3	****	Buyer j	****	Buyer n
Sales Quantity	y_{1opt}	y_{2opt}	y_{3opt}	****	y_{jopt}	****	y_{nopt}
Contract price	W_{1opt}	W_{2opt}	W_{3opt}	****	W_{jopt}	****	W_{nopt}
Sales price	$P(y_{1opt})$	$P(y_{2opt})$	$P(y_{3opt})$	****	$P(y_{jopt})$	****	$P(y_{nopt})$
Optimal Outsourcing quantity	'o_{yopt}'						

Table 4. Optimal operating parameters

5.3 GA Based heuristics for MV_MBO

The mathematical model formulated for the determination of 'x_{ijopt}' *(for* $\forall i, \forall j$*)* to the MV_MBO belongs to Mixed Nonlinear Integer Programming (MNIP) problem. The objective function is nonlinear involving *'n'* mixed integer variables and one linear constraint for sales quantity of buyers. The Hessian matrix of the objective function confirms the nature of it as non-convex (Ravindran *et al.*, 2000). LINGO optimization solver can be used to solve such MNIP problem of smaller in size. Yokota *et al.* (1996) presented the usefulness of GA for MNIP problems to provide optimal or near optimal solutions. Costa & Oliveira (2001) addressed that evolution strategies such as GA, SAA and ES are emerging as the best algorithm for MNIP problems. Mccall (2005) stated that one of the most attractive features of the GA is its flexibility on handling various objective functions with fewer requirements for fine mathematical properties. Taking into account the above concerns, GA based heuristics is proposed to evolve optimal or near optimal transaction quantity 'x_{ijopt}' *(for* $\forall i, \forall j$*)* for maximum channel profit to the MV_MBO model. The optimal Outsourcing transaction quantity 'Ox_{ijopt}', optimal sales price $P(y_{jopt})$ *(for* $\forall j$*)*and optimal contract price 'W_{ijopt}'*(for* $\forall i, \forall j$*)* are derived subsequently with the 'x_{ijopt}' *(for* $\forall i, \forall j$*)* obtained through GA. Flow chart given in figure 11. outlines the structure of the various modules of the proposed GA based heuristic and are explained briefly in this section .

5.3.1 Input module

Table 5 -7 shows the input data sets of MV_MBO problem. They are given as input in this module.

Parameters	Buyer						
	1	2	3	….	j	….	n
Holding cost	H_{b1}	H_{b2}	H_{b3}	….	H_{bj}	….	H_{bn}
Order / Setup Cost	S_{b1}	S_{b2}	S_{b3}	….	S_{bj}	….	S_{bn}
Intercept	a_1	a_2	a_3	….	a_j	….	a_{jn}
Cost slope	b_1	b_2	b_3	….	b_j	….	b_n
Minimum sales quantity	y_{1min}	y_{2min}	y_{3min}	….	y_{jmin}	….	y_{nmin}
Maximum sales quantity	y_{1max}	y_{2max}	y_{3max}		y_{jmax}	….	y_{nmax}

Table 5. Buyer related data

Parameters	Vendor						
	1	2	3	….	i	….	m
Holding cost	H_{S1}	H_{S2}	H_{S3}	….	H_{Sj}	….	H_{Sm}
Order / Setup Cost	S_{S1}	S_{S2}	S_{S3}	….	S_{Sj}	….	S_{Snm}
Capacity	C_1	C_2	C_3	….	C_i	….	C_m
Production cost per unit	δ_1	δ_2	δ_3	….	δ_i		δ_m
Outsourcing cost parameter	λ_1	λ_2	λ_3	….	λ_i	….	λ_m

Table 6. Vendor related data

Parameters	Vendor	Buyer						
		1	2	3	….	j	….	n
Revenue Share Ratio	1	PR_{11}	PR_{12}	PR_{13}	….	PR_{1j}	….	PR_{1n}
	i	PR_{i1}	PR_{i2}	PR_{i3}	….	PR_{ij}	….	PR_{in}
	m	PR_{m1}	PR_{m2}	PR_{m3}	….	P_{mj}	….	PR_{mn}
Flow cost per unit	1	θ_{11}	θ_{12}	θ_{13}	….	θ_{1j}	….	θ_{1n}
	i	θ_{i1}	θ_{i2}	θ_{i3}	….	θ_{ij}	….	θ_{in}
	m	θ_{m1}	θ_{m2}	θ_{m3}	….	θ_{mj}	….	θ_{mn}

Table 7. Common data between vendor and buyer

5.3.2 Initialization module

This module generates the chromosomes of initial population. Each chromosome 'c' represents the randomly generated sales quantities of all buyers with the j^{th} gene indicating the sales quantity 'y_j' of buyer 'j'. The procedure for initialisation of random sales quantity of all buyers is similar to the one expressed in section 5.2.2.

The size of the population depends on the feasible solution space of the problem, which is normally dependent on the number of decision variables (Michalewicz, 1994). Under this consideration, the population size (*pop_size*) is set as the twice the number of buyers (i.e. *pop_size* =2n).

5.3.3 Allocation module

In this module, the transaction quantities are allocated between the vendors and the buyers basing on the following steps

i. *Decoding of chromosomes:* The chromosome *'c'* is decoded to provide feasible sales quantity (y_j) *(for* $\forall j$*)*

ii. *Allocation of transaction quantity:* Transaction quantity (x_{ij}) are allocated between vendor *'i'* and buyer *'j'* based on vendor capacity (C_i) and buyer sales quantity (y_j) using north west corner rule.

5.3.4 Evaluation module

In this module, the population is evaluated and the probability of selection of each chromosome is found out. Maximisation of channel profit P_c' is considered as an evaluation criterion. Each and every chromosome is tested for its fitness based on the following steps given below for the next generation.

i. *Determination of fitness parameter value:* The fitness parameter '*fit(c)*' is the channel profit P_c and is calculated using equation (35) for chromosome *'c'* by substituting the feasible sales quantities 'y_j'

ii. *Conversion of fitness parameter value to new fitness parameter value:* This step converts the fitness parameter to a new fitness value '*newfit(c)*' suitable for the maximization objective and scaling them high, so that a very few extremely superior individuals would be selected as parents too many times. Selecting the best conversion function can be some what problem dependant. However, one function that has been found to generally useful is the exponential (Masters, 1993).

i.e., $$\text{new fit}(c) = e^{\,k\text{fit}(c)} \tag{42}$$

Where k is constant and the value of the constant is usually set by trails in order to scale the fitness function reasonably to retain at least half of the good chromosomes in the population find place in the new population. Hence the new fitness parameter value is set as:

$$\text{new fit}(c) = e^{0.0005\text{fit}(C} \tag{43}$$

iii. *Conversion of new fitness to an expected frequency of selection:* The final evaluation step is to convert the new fitness parameter to an expected frequency / probability of selection *(p(c))* of chromosome '*c*' by the sum of the new fitness values of all chromosomes.

i.e., $$p(c) = \text{new fit}(c) \Big/ \sum_{c=1}^{c=pop\_size} newfit(c) \tag{44}$$

5.3.5 Sorting module

In this module, the maximum fitness parameter is sorted out for each population and it will be stored as the local best. The maximum value is sorted out after all iterations and it is stored as the Global best.

5.3.6 Termination criterion

Termination criterion is checked after sorting module to know whether the pre-determined number of iterations is completed. On its completion, the algorithm passes to the output module, otherwise, the new set of population is generated as given in the new population generation module. The number of generations (iterations) depends upon the nature and size of the problem and is fixed by user.

5.3.7 New population generation module

Selection of next population is based on survival probability, crossover to produce children and mutation to induce external influence in new generation.

5.3.7.1 Selection module

The next population of the same size is obtained with random selection with the help of a roulette wheel procedure of which is explained here below. First the cumulative probabilities of selection / survival '*cp(c)*' of all the chromosomes are found out.

i.e.,
$$\mathrm{cp(c)} = \sum_{c=1}^{c=c} \mathrm{p(c)} \tag{45}$$

Then the random number '*r*' between 0 and 1 is generated and a chromosome '*c*' is selected, satisfying the following condition:

$$\mathrm{cp(c)} \geq \mathrm{r} > \mathrm{cp(c\text{-}1)} \tag{46}$$

This selection process is repeated as many times as equal to population size. This method used here is more reliable because, it guarantees that most fit individuals will be selected, and that the actual number of times each chromosome selected will be within one of its expected frequency. This procedure enables fit chromosome to get multiple copies and the worst chromosome to die off.

5.3.7.2 Crossover module

This involves two steps, viz., (i) selection of chromosome for crossover and (ii) cross over operation. Probability of crossover '*p_cross*' is a vital parameter in cross over operation. The value for *p_cross* is assumed as 0.6 so that atleast 60 % of chromosomes selected in the earlier selection module will undergo crossover operation and produce offspring. The procedure for this selection is as follows: Random numbers between 0 and 1 are generated for all chromosomes, and those chromosomes with random numbers less than *p_ cross* value are the chromosomes selected for crossover. If the number of selected chromosomes is odd, then the above procedure is repeated until one more chromosomes get selected and the number of selected chromosomes becomes an even number.

The next step is to carry the crossover operation, a reproduction method. There are so many cross operations (Michalewicz, 1994). This work uses simple single point cross over. In which a cutting point is introduced at random, which splits the selected chromosomes into two parts into left and right. The right parts of the parent chromosomes are swapped to produce two new off springs. This process is continued for all the chromosomes selected for crossover.

5.3.7.3 Mutation module

The purpose of mutation is the introduction of new genetic material, or the recreation of good genes that were lost by chance through poor selection of mates. To do this effectively, the effect of mutation must be profound. At the same time, the valuable gene pool must be protected from wanton destruction. Thus, the probability of mutation '*p_mut*' should be tiny (Masters, 1993). On the above grounds, the value of '*p_mut*' is assumed as 0.03 in this chapter. The procedure followed for mutation is as follows: Random number is generated for each gene in the population; the genes that get random number '*r*' less than '*p_ mut*' undergo mutation; the selected genes are mutated by replacing 'ONE' to 'ZERO' and vice versa.

5.3.8 Output pricing module

After completion of all iterations, the '*global best*' fitness parameter sorted out is considered as the optimal channel profit 'P_{copt}' and its corresponding optimal sales quantity of all buyers is 'y_{jopt}'. This module derives the optimal sales price '$P(y_{jopt})$' and acceptable contract price 'W_{jopt}' for the optimal quantity 'y_{jopt}' determined from the previous module. Sales price for each buyer is calculated using the equation (39) and contact price for each buyer is calculated using equation (40). Complete output obtained is shown in Table 8 for the optimal channel profit '$P_{c\,opt}$'.

Operating Parameters		**Buyer**								
		1			j			n		
		x_{ij}	Ox_{ij}	W_{ij}	x_{ij}	Ox_{ij}	W_{ij}	x_{ij}	Ox_{ij}	W_{ij}
Supplier	1	x_{11opt}	Ox_{11opt}	W_{11opt}	x_{1jopt}	Ox_{1jopt}	W_{1jopt}	X_{1nopt}	Ox_{1nopt}	W_{1nopt}
	i	x_{i1opt}	Ox_{i1opt}	W_{i1opt}	x_{ijopt}	Ox_{ijopt}	W_{ijopt}	x_{inopt}	Ox_{inopt}	W_{inopt}
	m	x_{m1opt}	Ox_{m1opt}	W_{m1opt}	x_{mjopt}	Ox_{mjopt}	W_{mjopt}	x_{mnopt}	Ox_{mnopt}	W_{mnopt}
Demand		y_1			y_j			y_{mn}		
Sales price		$P(y_{1opt})$			$P(y_{jopt})$			$P(y_{nopt})$		
Channel profit		P_{copt}								

Table 8. Optimal operating parameters

6. Illustration

This section illustrates the GA based heuristic proposed for MV_MBO model with a pilot study data from agricultural development offices situated at three rural places of south India. The landowners (vendor) supply rice grains to these agricultural development offices. The agricultural development offices (buyers) supply their products (rice grains) to the customers. This section illustrates the proposed methodology only with 2 vendors and three buyers and it can as well be extended, to '*m*' vendors and '*n*' buyers. The vendor is currently operating in independent mode where the buyers initiate the orders everyday. Based on the orders, the vendors supply the required quantities to buyers. Table 9, 10 and 11 provide the buyer related data, vendor related data and the common data between vendor and buyers respectively.

y_j	**1**	**2**	**3**
H_{bj}	2	1	2
S_{bj}	5	5	7
a_j	23	22	21
b_j	0.0001	0.0002	0.0003
y_{jmin}	1000	2000	1000
y_{jmax}	2000	3000	3000

Table 9. Buyer related data

i	H_{si}	S_{si}	C_i	δ_i	λ_i
1	2	10	3000	15	0.2
2	1	9	3000	16	0.2

Table 10. Vendor related data

Parameters	*I*	*j*		
		1	**2**	**3**
PR_{ij}	1	*1.2*	*1.1*	*1.3*
	2	*1.2*	*1.2*	*1.1*
θ_{ij}	1	*0.004*	*0.002*	*0.005*
	2	*0.005*	*0.003*	*0.002*

Table 11. Common data between vendor and buyer

Various modules of the GA heuristic are shown in Tables 12 to 19 respectively, and the optimal parameters for the case problem are shown in Tables 20. The GA parameters used are as follows: chromosome length = 27, pop_size =12, *p_cross* = 0.6, *p_mut*=0.03, number of iterations = 100.

c	**Chromosomes**																										
1	1	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	1	0	0	1	1	1	0	1	0	0	1
2	0	0	1	0	1	0	1	1	0	0	1	0	1	1	1	1	1	1	0	0	1	0	1	0	1	1	0
3	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1
4	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	1	0	0	1	1
5	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	1	0	1	1	1	1
6	1	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0
7	0	1	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	1	1	1	0	0	1	0	0	0	0
8	1	1	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	0	1	1	0	1	1	0	1	1	0
9	1	1	1	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0
10	1	1	1	0	1	1	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	0
11	0	1	1	0	1	1	0	1	0	1	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	0
12	0	1	0	1	1	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	0	0	1	0	1	0	1

Table 12. Initial population of chromosomes

c	y_j			fit(c)	newfit (c)	P (c)
	1	2	3			
1	1504	2919	1911	22527.23	32621.34	0.056
2	**1168**	**2373**	**1336**	**23073.63***	45517.29	0.079
3	1841	2788	2475	22706.20	53400.18	0.092
4	1984	2493	2577	22150.13	45697.27	0.079
5	1923	2183	1183	22398.5	51181.93	0.088
6	1761	2185	2432	22222.8	58623.6	0.101
7	1446	2111	2565	21979.21	72326.35	0.125
8	1833	2864	2714	21989.09	30547.52	0.053
9	1956	2722	1046	21627.15	65408.42	0.113
10	1931	2144	2714	21098.45	50323.69	0.087
11	1426	2524	2189	21765.37	16496.19	0.028
12	1350	2735	2585	21542.8	53027.41	0.092

*Local Best

Table 13. Parameters for the generation of new population

c	cp(c)	R	Selected
1	0.056	0.21	1′ (9)
2	0.135	0.03	2′ (3)
3	0.228	0.21	3′ (3)
4	0.308	0.97	4′(7)
5	0.397	0.91	5′(9)
6	0.499	0.66	6′(3)
7	0.624	0.51	7′(7)
8s	0.677	0.11	8′(7)
9	0.791	0.78	9′(9)
10	0.879	0.9	10′(9)
11	0.907	0.28	11′(3)
12	1	0.9	12′(7)

Table 14. New population before crossover and mutation

C′	r	S /NS*
1′	0.62	NS
2′	0.44	S
3′	0.86	NS
4′	0.79	NS
5′	0.12	S
6′	0.99	NS
7′	0.93	NS
8′	0.24	S
9′	0.75	NS
10′	0.71	NS
11′	0.01	S
12′	0.91	NS

*S: Selected / NS: Not Selected

Table 15. Selection of chromosome for crossover

c′	Parents																										
2′	0	0	1	0	1	0	1	1	0	0	1	0	1	1	1	1	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**0**
5′	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	1	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**
8′	1	1	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**0**
11′	0	1	1	0	1	1	0	1	0	1	0	0	0	0	1	1	0	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**

Table 16. Parents selected for cross over

c″	Parents																										
2″	0	0	1	0	1	0	1	1	0	0	1	0	1	1	1	1	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**1**
5″	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	1	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**0**
8″	1	1	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
11″	0	1	1	0	1	1	0	1	0	1	0	0	0	0	1	1	0	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**0**

Table 17. Off springs of selected parents

c′/c″	Chromosomes																										
1′	1	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	1	0	0	1	1	1	0	1	0	0	1
2″	0	0	1	0	1	0	1	1	0	0	1	0	1	1	1	1	1	0	0	0	0	1	0	1	1	1	1
3′	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1
4′	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	1	0	0	1	1
5″	1	1	1	0	1	1	0	0	0	0	0	1	0	1	1	1	1	1	0	0	1	0	1	0	1	1	0
6′	1	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0
7′	0	1	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	1	1	1	0	0	1	0	0	0	0
8″	1	1	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0
9′	1	1	1	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0
10′	1	1	1	0	1	1	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	0
11″	0	1	1	0	1	1	0	1	0	1	0	0	0	0	1	1	0	0	1	1	0	1	1	0	1	1	0
12′	0	1	0	1	1	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	0	0	1	0	1	0	1

Table 18. Chromosomes after cross over and before mutation

c‴	Chromosomes																										
1‴	1	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	1	0	0	1	1	1	0	1	0	0	1
2‴	0	0	1	0	1	0	1	1	0	0	**0**	0	1	1	1	1	1	0	0	0	0	1	0	1	1	1	1
3‴	1	1	0	1	0	1	1	1	0	1	1	0	0	1	0	0	1	1	1	0	**0**	1	1	1	0	0	1
4‴	1	1	1	1	1	**1**	1	1	1	0	1	1	1	1	1	1	0	0	1	1	0	0	1	0	0	1	1
5‴	1	1	1	**1**	1	1	0	0	0	0	0	1	0	1	1	1	1	1	0	0	1	**1**	1	0	1	1	0
6‴	1	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0
7‴	0	1	1	1	**1**	0	1	0	0	0	0	0	1	1	1	0	0	1	1	1	0	**1**	**0**	0	0	0	0
8‴	1	1	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	0	1	0	0	1	1	0	0	0	0
9‴	1	1	1	1	**1**	1	**1**	0	1	1	0	1	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0
10‴	1	1	1	0	1	1	1	0	0	0	0	1	0	0	1	0	1	0	1	**0**	0	1	1	0	1	1	0
11‴	0	1	1	0	1	1	0	**0**	0	1	0	0	0	0	1	1	0	0	1	1	0	1	1	0	1	1	0
12‴	0	1	0	1	1	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	0	0	1	0	1	0	1

* Mutated genes are shown as bold

Table 19. New Population (Population of chromosome after mutation)

<table>
<tr><th colspan="2" rowspan="3">Operating Parameters</th><th colspan="9">Buyer 'j'</th></tr>
<tr><th colspan="3">1</th><th colspan="3">2</th><th colspan="3">3</th></tr>
<tr><th>x_{ijopt}</th><th>Ox_{ijopt}</th><th>W_{ijopt}</th><th>x_{ijopt}</th><th>Ox_{ijopt}</th><th>W_{ijopt}</th><th>x_{ijopt}</th><th>Ox_{ijopt}</th><th>W_{ijopt}</th></tr>
<tr><td rowspan="2">Supplier 'i'</td><td>1</td><td>1363</td><td>0</td><td>20.66</td><td>1637</td><td>0</td><td>19.38</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>0</td><td>0</td><td>0</td><td>1362</td><td>0</td><td>20.14</td><td>1638</td><td>276</td><td>19.32</td></tr>
<tr><td colspan="2">Sales quantity</td><td colspan="3">1363</td><td colspan="3">2999</td><td colspan="3">1914</td></tr>
<tr><td colspan="2">Sales price</td><td colspan="3">22.86</td><td colspan="3">21.4</td><td colspan="3">20.42</td></tr>
<tr><td colspan="2">Channel profit</td><td colspan="9">22724.52</td></tr>
</table>

Table 20. Optimal operating parameters

7. Concluding remarks

7.1 Summary

This section reports the robustness of the model and methodology, limitation, in the current research, managerial implications and potential scope for future research. This chapter addressed to the soft issues of profit sharing and pricing in SCM and has concentrated on development of decision support heuristics to determine the optimal or near optimal operational parameters (Sales quantities, Prices (sales and contract) and outsourcing quantities and transaction quantities) for maximum channel profit to the two-echelon SC models operating under VMI mode.

i. Single Vendor Single Buyer (SV_SB)
ii. Single Vendor Multiple Buyer's (SV_MB)
iii. Multiple Vendors Multiple Buyers (MV_MB)
iv. Single Vendor Multiple Buyer's with Outsourcing (SV_MBO)
v. Multiple Vendors Multiple Buyers with Outsourcing (MV_MBO)

Furthermore, this chapter illustrated application of VMI systems for two-echelon SC models in the agricultural sector. Fixation of contract price for the different revenue ratio is a tedious process, which leads to conflicts between partners, if it is not properly adopted in VMI system. To overcome the above limitation, a new methodology is required to determine the contract prices for known revenue shares between vendor and buyer. Hence, this chapter proposes an iterative heuristic procedure for SV_SB model to find optimal or near optimal operational parameters. The mathematical formulation of the remaining four models (SV_MB, MV_MB, SV_MBO, MV_MBO) belongs to Nonlinear Integer Programming (NIP) and Mixed Integer Nonlinear Programming (MINP) problems. The Hessian matrix of the objective functions confirms the nature of it as non-convex. Hence GA and SAA based heuristics are proposed to solve the above models.

Iterative heuristic procedure provides optimal/near optimal solution when compared with the methodology proposed by Dong & Xu (2002) for the same SV_SB operating in VMI mode of operation, but under equal revenue share cases. GA and SAA based heuristics provides near optimal solution when compared with i) LINGO optimization solver for smaller size problems ii) DX methodology of Dong & Xu (2002) by reducing the models (2-5) into SV_SB. The computational time increases with increase in number of vendors and buyers. However the problem is static and justifiable.

The robustness of the models are evaluated by changing the influencing parameters such as limits on sales quantity, slope of demand function, cost of holding and cost of setup/order. Variation in holding and order setup cost has less impact in sales quantities, sales price and contract price, whereas it has more impact on the channel profit. Variations in limits on sales quantity and slope of demand pattern have more impact on operational parameters and channel profit. Hence it is concluded that the model presented, the heuristics proposed and the analysis carried out in this chapter work would aid SC managers to take appropriate decision in two- echelon VMI systems.

7.2 Future directions

- Inventory holding cost and order setup cost for vendor in all the above models are assumed as sum of both holding cost and order setup cost, but in practice the inventory cost will be less. Therefore the vendor profit and channel profit would be more in real time. Future analysis can consider various combination of inventory holding and order setup cost to the above models and the insight of the problem could be studied.
- The distribution cost in all the models varies parabolically depending upon the increase in quantity and mode of transportation. Since in VMI, the vendor has to monitor inventory and to replenish products as and when required, there will be exponential variation in distribution cost depending upon the increase in quantity and mode of transportation. Hence future research can represent distribution cost with respect to product and incorporate fixed transportation cost to depict the real cost of transportation.
- All the above models assume reverse linear relationship between price-sales quantities. The impact on optimal operational parameters for various demand curves can be studied for other categories of product.
- The mode of operation assumes zero lead time and would not allow backlog and stock out. Researchers in future can accommodate these factors along with shortage cost for varying service levels while developing two-echelon models.
- Concept of heuristics proposed for two-echelon models could be extended for multi echelon models
- This chapter illustrated the development of heuristics for sectors like agriculture, but this can be extended to any kind of product and service sectors such as milk, engineering services etc.
- Development of knowledge managed systems for two-echelon VMI systems to determine operational parameters for maximum channel profit based on the experts experience and with the data available from the market.
- The other soft issues such as organizational resistance to change, inter-functional conflicts, team oriented performance measures and channel power shift have not been considered while modelling two-echelon SC. Hence future researchers may pay more attention to these issues.

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Nomenclature

a	Constant.
a_j	Intercept value for the demand pattern of the j^{th} buyer
b	Slope of Demand pattern – Selling Price Curve.
b_j	Cost Slope of the demand pattern of the j^{th} buyer
c, c', c'', c'''	Chromosome
C	Capacity of the vendor
C_i	Capacity of the vendor 'i'
$cp(c)$	Cumulative probability of survival
$cp(c\text{-}1)$	Cumulative probability of survival of previous chromosome
EOQ	Economic order quantity
EOQ_j	Economic order quantity of j^{th} buyer
EOQ_{ij}	Economic order quantity from i^{th} vendor to j^{th} buyer
F	Frame work
$fit(c)$	Fitness function
H_b	Holding cost per unit per unit time of the buyer in independent mode of operation.
H_{bj}	Holding cost of the j^{th} buyer in independent mode
H_S	Holding cost per unit per unit time of the vendor in independent mode of operation.
H_{Si}	Holding cost of the vendor 'i' in independent mode
H_{VMI}	Inventory cost of vendor per unit per unit time in VMI mode of operation.
H_{jVMI}	Holding cost of the vendor in VMI mode
H_{ijVMI}	Holding cost of the vendor 'i' to j^{th} buyer in VMI mode
i	Vendor identifier (i= 1 to m)
j	Increment factor for sales quantity.
m	Number of vendors
n	Number of the buyers
$newfit(c)$	New fitness function
OSM	Order and stock maintenance cost to the vendor for buyer

OSM_j	Order and stock maintenance cost to the vendor for each buyer
OSM_{ij}	Order and stock maintenance cost to the vendor *'i'* for each buyer *'j'*
Ox	Outsourcing transaction quantity
Ox_{ij}	Outsourcing transaction quantities between vendor *'i'* and buyer *'j'*
Ox_{ijmin}	Minimum outsourcing transaction quantities between vendor *'i'* and buyer *'j'*
Ox_{ijmax}	Maximum outsourcing transaction quantities between vendor *'i'* and buyer *'j'*
Ox_{ijopt}	Optimal outsourcing transaction quantities between vendor 'i' and buyer 'j'
OCx_{ij}	Outsourcing cost from i^{th} vendor to j^{th} buyer
o_y	Outsourcing quantity
o_{yopt}	Optimal outsourcing quantities
o_c	Outsourcing cost of the vendor
o_{cj}	Outsourcing cost of the vendor to j^{th} buyer ($o_{cj}=o_c/n$)
p_cross	Probability of the cross over
P	Pricing
P_b	Buyer Profit under Independent mode of operation
P_b'	Buyer Profit in VMI mode
P_{bj}	Profit of j^{th} buyer in VMI mode
P_c	Channel profit in independent mode
$P_{c'}$	Channel profit in VMI mode
P_c''	Channel profit obtained after perturbation in Simulated annealing
ΔP_c	Difference in Channel Profit
P_{copt}	Optimal channel profit in VMI mode
P_s	Vendor Profit under Independent mode of operation.
P_s'	Vendor Profit in VMI mode
P_{si}	Profit of vendor *'i'* in VMI mode
P_{sj}	Profit obtained by vendor when supplying products to the buyer *'j'* in VMI mode
P_{sij}	Profit obtained by vendor *'i'* when supplying products to the buyer *'j'*
PD	Production distribution cost of the buyer.
PD_j	Production distribution cost of the j^{th} buyer.
PD_{ij}	Production distribution cost from i^{th} vendor to the j^{th} buyer.
$p(c)$	Probability of survival of chromosome 'c'
p_mut	Probability of mutation
pop_size	Population size
$P(y)$	Sales Price

$P(y_j)$	Sales price of the j^{th} buyer corresponding to sales quantity 'y_j'
$P(y_{opt})$	Sales price at optimal sales quantity $y_{opt.}$
$P(y_{jopt})$	Optimal sales price of the j^{th} buyer
$PR_{non\text{-}VMI}$	Revenue share ratio between vendor and buyer when they operate under non -VMI mode (P_s/ P_b).
PR	Revenue share ratio between vendor and buyer when they operate under VMI mode (P_s'/ P_b').
PR_j	Revenue share ratio between vendor and the j^{th} buyer
PR_{ij}	Revenue share ratio between i^{th} vendor and the j^{th} buyer
$P_c'(y)$	Channel Profit for quantity y in VMI mode of operation.
$P_c'(y - \Delta y)$	Channel Profit of VMI mode for the prior incremental value of sales quantity
Q	Replenishment quantity
Q_j	Replenishment quantity to each buyer 'j'
Q_{ij}	Replenishment quantity from vendor 'i' to buyer 'j'
r	Random number
S_b	Setup cost per order of the buyer in Independent mode of operation.
S_{bj}	Setup cost of the j^{th} buyer per order in independent mode
S_S	Setup cost of the vendor per order in independent mode
S_{Si}	Setup cost of the vendor 'i' per order in independent mode
S_{VMI}	Set up cost per order of the vendor in VMI mode of operation.
S_{jVMI}	Setup cost of the vendor per order in VMI mode of operation to buyer 'j'
S_{ijVMI}	Setup cost of the vendor 'i' per order in VMI mode of operation to buyer 'j'
T	Temperature
$t1,t2$	Random numbers generated in Simulated Annealing for perturbation
W	Contract price
W_j	Contract price between vendor and buyer 'j'
W_{ij}	Contract price between vendor 'i' and buyer 'j'
W_{opt}	Optimal Contract price.
W_{jopt}	Optimal contract price between vendor and buyer 'j'
W_{ijopt}	Optimal contract price between vendor 'i' and buyer 'j'
x	Transaction quantity
x_{ij}	Transaction quantities between vendor 'i' and buyer 'j'
x_{imin}	Minimum transaction quantities between vendor 'i' and buyer 'j'
x_{ijmax}	Maximum transaction quantities between vendor 'i' and buyer 'j'
x_{ijopt}	Optimal transaction quantities between vendor 'i' and buyer 'j'
y	Sales quantity

y_j	Sales quantity of the j^{th} buyer (i.e. $y_j = \sum_{i=1}^{m} x_{ij}$)
Y	Aggregate sales quantity of the vendor (i.e. $y = \sum_{j=1}^{n} y_j$)
y_i	Aggregate sales quantity of the vendor 'i' (i.e. $y_i = \sum_{j=1}^{n} y_j$)
y_j'	Sales quantity obtained after perturbation in Simulated annealing of the j^{th} buyer
y_{min}	Minimum expected sales quantity.
$y_{j\,min}$	Minimum expected sales quantity of the j^{th} buyer
y_{max}	Maximum expected sales quantity
$y_{j\,max}$	Maximum expected sales quantity of the j^{th} buyer
y_{opt}	Optimal sales quantity.
y_{jopt}	Optimal sales quantity of the j^{th} buyer
θ	Flow cost per unit from vendor to buyer.
θ_j	Flow cost per unit from vendor to buyer 'j'
θ_{ij}	Flow cost per unit from vendor 'i' to buyer 'j'
υ	Transportation resource cost per unit from vendor to buyer
υ_j	Transportation resource cost per unit from vendor to buyer 'j'
υ_{ij}	Transportation resource cost per unit from vendor 'i' to buyer 'j'
δ	Production cost per unit
δ_i	Production cost per unit for vendor 'i'
α	Temperature factor
β	Outsourcing factor
Δy	Incremental change in sales quantity
β_{ij}	Outsourcing factor between vendor 'i' and buyer 'j'
η	Outsourcing cost constant
λ	Additional outsourcing cost
λ_i	Additional outsourcing cost for vendor 'i'

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Transshipment Problems in Supply ChainSystems: Review and Extensions

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1. Introduction

Effective supply chain management (SCM) is currently recognized as a key determinant of competitiveness and success for most manufacturing and retailing organizations, because the implementation of supply chain management has significant impact on cost, service level, and quality. Numerous strategies for archiving these targets have been proposed and investigated in both practice and academic over the past decades. One such strategy, commonly practiced in multi-location supply chain systems facing stochastic demand, allows movement of stock between locations at the same echelon level or even across different levels. These stock movements are termed lateral transshipments, or simply, transshipments. As a demand occurs under the implementation of transshipment strategy, there will be three possible activities—the demand is met from the stock on-hand or it is met via transshipment from another location in the system or it is backordered. In another words, firstly, if a location's on-hand inventory level is greater than the demand size, then the demand is met. Secondly, if the on-hand inventory level is positive but less than the demand size, then it is used to partially satisfy the demand and the remaining demand is met either via transshipment or is backordered. Thirdly, if the on-hand inventory level is zero, the demand is met via transshipment or is backordered under the assumption of no lost sale. In addition to the same echelon level transshipment, when neither one location's same level partners in the same region nor its designated supplier/warehouse/or distribution center lack sufficient inventory to meet the demand, the unmet remaining demand can be fulfilled from the upper-level supplier which may not belong to the same geographical region. This practice is defined as cross-level transshipment. The illustration of transshipment is depicted in Figure 1. Therefore, transshipment policy can improve stock availability, i.e., customer service level, without increasing stock level which may induce higher inventory relevant cost. In another words, transshipments enable the sharing of stock among locations, they facilitate each location as a secondary, random supply source for the remainder. Thus, the locations' replenishment can be coordinated and even combined in order to avoid excessive inventory costs.

Transshipment research is motivated by observations from various industries. It has gained increasingly attention in medicine, apparel, and fashion goods, particularly by those retailers with brick and click outlets, or critical repairable spare parts of equipment-intensive industries such as airlines, nuclear power plants, and complex machines. They are also suitable for retailers that require long replenishment lead times from suppliers located closer to each other or spend significant funds on construction and operation of storage facilities to prevent costly shortage penalty.

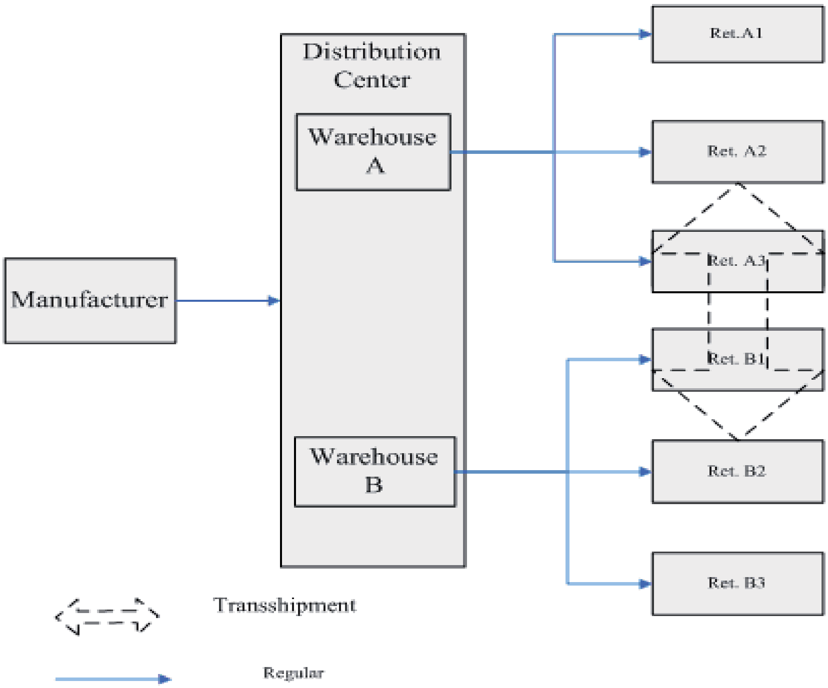

Figure.1 Transshipment in a supply chain system

One of the prerequisite of successful implementation of transshipment is well-established information systems. At present many large modern companies connected by information systems can control the relationships of many branches, and thus they may be ready to reap cost reduction and service improvement associated with lateral transshipment.

In the past decades, a considerable amount of research has been dedicated to this field. The list of research papers dealing with transshipments to date is quite long and no attempt is made here to exhaust it. In this chapter we mainly focus on presenting a comprehensive description, classification, methodologies and solution procedures, and research directions for further study of transshipment in supply chain system. (Köchel, 1998) conducted a preliminary survey on transshipment, however, a considerable amount of research over the past decade have not been covered. The main aim of this paper is to present a systematic survey on the development of transshipment studies.

This chapter is organized as follows. In Section 2, we introduce the characteristics of the transshipment problem. We identify the scope, introduce the basic assumptions, explain the elements of the transshipment policy, introduce the common inventory control policies, and define the performance measurement. Section 3 classifies the transshipment problems based on the characteristics that we prescribe in Section 2. In Section 4, we classify the methodologies and solution procedures for transshipment problems into two categories. In Section 5, we summarize the significance of this paper and address the existing and possible extensions of transshipment and propose directions for further research.

2. Characteristics of transshipment

2.1 Scope

Effective supply chain management (SCM) has become an important management paradigm. A great amount of studies have shown that substantial benefits can be obtained from SCM. Basically, SCM is a effective and systematic approach of managing the entire flow of information, material and services in fulfilling a customer demand (Chase, 1998). In this chapter we are mainly focused on material flow management in the supply chain system. At present many quantitative models have been proposed to provide decision support for the management of materials in supply chains (see, Tayur et al., 1998). Moreover, since the network of entities that constitute the entire supply chain is typically too complex to analyze and optimize globally, it is often desirable to focus on smaller parts of the system so as to gain a in-depth understanding of its characteristics, performance and tradeoffs involved. One such part that is attracting growing attention is the local distribution network, consisting of multiple retail outlets (stocking locations), which are supplied by one or more sources.

The overall performance of the distribution network, whether evaluated in economic terms or in terms of customer service, can be substantially improved if the retailers collaborate in the occurrence of unexpectedly high demand, which may result in shortages in one or more retailing outlets. Collaboration usually takes the form of lateral inventory transshipment from a stock outlet with a surplus of on-hand inventory to another outlet that faces a stockout. Since the cost of transshipment in practice is generally lower than both the shortage cost and the cost of an emergency delivery from the designated warehouse and the transshipment time is shorter than the regular replenishment lead time, lateral transshipment simultaneously reduces the total system cost and increases the fill rates at the retailers. A group of stocking locations that share their inventory in this manner is to form a pooling group, since they effectively share their stock to reduce the risk of shortages and provide better service at lower cost.

There is a considerable amount of literature on SCM over the past decades. Some papers have provided literature survey for some specific topics. For example, (Ganeshan et al., 1998) provided a taxonomic review of the SCM research in three categories: competitive strategies, firm-focused tactics, and operational efficiency. (Tsay et al., 1998) reviewed the recent literature on supply chain contracts. (Tan, 2001) provided a review of the evolution of the SCM philosophy. (Sahin & Robinson, 2002) provided a review of the prior research on information and physical flow coordination. (Li & Wang, 2007) focused on coordination mechanisms that can align the objectives of individual supply chain members. This paper mainly concentrates on an analysis of the operation of transshipment in a group consisting of multiple retailing outlets and a single/or multiple upper sources in a two-echelon supply chain system.

Other researchers have also examined the effectiveness of lateral shipments for Repairable or recoverable items (e.g. Lee, 1987; Axsäter, 1990; Wong et al., 2005 & 2006), while still others have focused on consumable products (see, e.g., Jonsson & Silver, 1987; Archibald et al., 1997; Cohen et al., 1986; Robinson, 1990).

2.2 Assumptions

There are several basic assumptions that are commonly seen in the literature of transshipment such as the behaviors of demand occurrence, transshipment time, repair time, and transshipping priority rule etc. They are stated as follows.

The behaviors of demand occurrence are usually characterized by the time between demands and the distribution of demand size. The time between demands is commonly assumed to follow an Exponential or Gamma distribution. However, the distributions of demand size per each demand occurrence depend on the characteristics of the investigated industry. For example, it was taken as Weilbull distribution for spare parts which have slow-moving, expensive and lumpy demand pattern (Kukreja & Schmit, 2005). (Needham & Evers, 1998) assume the normal distribution truncated at zero for military spare parts. A drawback of using the normal distribution is that it is less appropriate for low volume items (Silver & Peterson, 1998); however, it does not place any restriction on the values of the mean and variance (compared to, say, the Poisson distribution which requires that they must be equal). In addition, its properties are well known and it is typically the basis for examining continuous demand. Besides, (Wong et al., 2006) assumed the demand occur according to Poisson process with constant rate for reparable parts in equipment-intensive industries such as, airlines, nuclear power plants, and manufacturing plants using complex machines. These industries are confronted with the challenge of maintaining high system availability, while limiting the costly spare parts inventory simultaneously. Furthermore, in a large amount transshipment literature the behaviors of demand are alternatively characterized by assuming what distribution the average demand per time period follows (e.g., Needham & Evers, 1998; Tagaras, 1999; Herer & Rashit, 1999; Burton & Banerjee, 2005; Wong et al., 2006).

The majority literature assumes transshipment time to be negligible. (Kukreja & Schmidt, 2005) considered that a large utility company has all locations in five adjoining southeastern states. A part can be transshipped between any two locations within a working day. This transshipment time is acceptable to the management and is treated as negligible. Because many spare parts are for machines like turbines, pulverizes, etc., substantial time is needed to take off the part from the machine and prepare it to receive the new part. If the new part can be supplied via transshipment within one day, then the assumption of negligible transshipment times is acceptable. At present only some papers account for the non-negligible transshipment time. The transshipment time are assumed to be shorter than emergency supply. In other words, lateral transshipments are faster and cheaper than emergency supplies because all firms in the pooling group should be at close distance to each other. Otherwise it makes no sense to pool the item inventories. Therefore, a lateral transshipment is always preferred over an emergency supply from time and cost perspectives.

(Gong & Yucesan, 2006) formulated a multi-location transshipment problem with positive replenish lead time. They used simulation optimization by combining an LP/Network flow in corporate with infinitesimal perturbation analysis (IPA) to analyze the problem, and obtains the optimal base stock quantities through sample path optimization. (Wong et al., 2005 & 2006) addressed the analysis of a multi-item, continuous review model of a multi-location inventory system of repairable parts with lateral transshipment and waiting time constraints, in which lateral and emergency shipments occur in response to stockouts. The objectives is to determine close-to-optimal stocking policies minimizing the total cost for inventory holding, lateral transshipments and emergency shipment subject to a target level for the average waiting times at all location. For the case of transshipment for spare parts, the repair time is usually assumed exponentially distributed. This assumption is probably not very realistic. However, (Axsäter, 1992) and (Alfredsson & Verrijdt, 1999) showed that the service performance of the system is insensitive to the choice of lead time distribution.

(Wong et al., 2005) showed that delayed lateral transshipments can improve the system performance. When a base having no backorders receives a repaired part and at the same time at least one base in the pooling group has backorders, it would be reasonable to send the repaired part to the base having backorders. Therefore, a delayed lateral transshipment occurs when the system has backorders and it is triggered by a repair completion.

One common transshipping priority rule for fulfilling the demands is assumed that a location receiving an order first satisfies its own backorder, if one exists, and then uses the remaining units to satisfy backorder(s) at other location(s) in a way that minimizes transshipping costs. The requested backorders are to be fulfilled according to first come first serve policy. However, if a transshipment request is indicated 1 day prior to the arrival time of the next cycle's shipment from the upper echelon, no lateral shipments are made in the current cycle, due to the anticipated delivery of a relative large quantity the following day.

In addition to the first come first serve of demand handling rule, (Zhao et al., 2006) investigated a decentralized dealer network where each dealer is willing share his inventory. They considered the inventory sharing with multiple demand classes. Assume that each dealer faces his own customer demand with higher priority and transshipment requests from other dealers with lower priority.

A significant amount of literature in transshipment assumed that complete pooling policy is to be applied. This is part of the agreement between the cooperating companies. When the demand at a location cannot be met from on-hand inventory, it is met via transshipment(s) from other outlet(s) in a way that minimizes the transshipping cost. A unit demand is backordered if it cannot be satisfied via transshipment, in other words when there are no units in the system. In case companies do not want to share their last parts, one may introduce threshold parameters, *aka* partial pooling, and agree that a company does not supply a part by a lateral transshipment if the physical stock of the requested item is at or below the threshold level. A rule has to be added for how the values of the threshold parameters are chosen, or one may consider them as additional decision parameters. In principle, this extended model may be analyzed along the same lines as our current model. (Cantagalli, 1987) and (Needham & Evers, 1998) classified the transshipment policy as complete pooling and partial pooling for lateral transshipment. The partial pooling transshipment will be addressed further in the next sub-section.

2.3 Transshipment policies

As the literature and practice suggested, there are two classes of transshipment. (Lee et al., 2007) proposed that lateral transshipment can be divided into two categories: emergency lateral transshipment (ELT) and preventive lateral transshipment (PLT). ELT directs emergency redistribution from a retailer with ample stock to a retailer that has reached stockout. However, PLT reduces risk by redistributing stock between retailers that anticipate stockout before the realization of customer demands . In short, ELT responds to stockout while PLT reduces the risk of future stockout. This concept of transshipment classification is similar to (Banerjee et al., 2003), wherein two kinds of policies were proposed: Lateral transshipment based on availability (TBA) and Lateral transshipment for inventory equalization (TIE). TBA transships stock to retailers with less than desirable levels until all stock is depleted. However, this policy is problematic when desired stock levels are determined incorrectly. TIE redistributes stock to match the target level of demand of each retailer whenever there are retailers with less than desirable stock levels. This policy does not respond to stockout after redistribution, because redistribution is performed once in every replenishment cycle. We will discuss these policies more in-depth and also address some recent developed transshipment rules in the following.

No lateral shipments (NLS) policy: In the literature NLS policy is usually used a baseline case for evaluating the effectiveness of the transshipment policies. Under this policy, no lateral transshipments are allowed. For example, at the end of each review cycle of 30 days, say, each retailer's order size is determined from its individual order-up-to level and this quantity is received only from the supplier after the supply lead time elapses. Total backordering is allowed at each retail outlet. The sales will be lost, if the unmet sales can not be backlogged. For such case, shortage cost will be incurred.

Lateral transshipments based on availability (TBA) policy: This implies that either all current transshipment needs have been met, or the total available transshipment quantity among all the excess locations has been exhausted. TBA, or called ELT, allows the transshipment decisions to be made more than once during a review cycle, based on the transshipment order point signal. TBA mandates emergency redistribution from a retailer with ample stock to a retailer that has reached stockout (Lee, 1987). (Lee, 1987) presented a model that allows TBA between local warehouses that are part of a group. If a local warehouse cannot satisfy customer demands with its on-hand stock, TBA is used to fill the demands from a warehouse in the same group that has enough stock on hand. If TBA is impossible due to group-wide stockout, the unmet demand will be backordered. (Lee, 1987) derived expressions that approximate the fractions of demands that can be satisfied by stock on hand, TBA, and backordering, and in doing so, proved that applying lateral transshipment reduces total cost. (Axsäter, 1990) analyzed a system similar to that of (Lee, 1987), but with the modification of assuming that warehouses within each group are not identical. (Axsäter, 1990) derived steady-state probability by assuming exponentially distributed replenishment time. Analytical results were compared with simulation results to show that, in the case of non-identical warehouses, the proposed model gives better results. (Tagaras & Cohen, 1992) investigated a model with two locations and non-zero replenishment lead time. (Rudi et al., 2001) investigated the conflict between maximizing location and system profits in a two-location model. These models assumed a non-negligible lead time on the service of customer requests to allow the total demand to become apparent before transshipments are arranged. In highly competitive retail situations, such a delay would often lead to lost sales. However, if a transshipment is requested 1 day prior to the arrival time of the next cycle's shipment from the upper-echelon supplier, no lateral shipments are made in the current cycle, due to it own nearly anticipated delivery of a relative large quantity the following day.

Lateral transshipments for inventory equalization (TIE) policy: Under this policy, the transshipment decisions are based on the concept of inventory balancing or equalization through stock redistribution. One of the first such models is due to (Gross, 1963) who characterized an optimal policy for a two-location system in which replenishment and transshipment decisions are taken together at the beginning of each period. (Das, 1975) analyzed a variant of this model in which the transshipment decision is taken at a fixed point during each period. (Jonsson & Silver, 1987) examined a model in which the objective is to minimize backorders rather than cost. The transshipment decision is taken a fixed time before the replenishment decision and the model allows for non-zero transshipment lead time and an arbitrary number of locations. In this case, as opposed to the TBA policy described above, inventory redistribution occurs no more than once in every review cycle.

There are three commonly used redistribution rules for TIE, or called PLT. Firstly, at the time of transshipment, inventories are redistributed among the retail locations through one or more lateral shipments, such that all locations will have an equal number of days' supply (or, alternatively, equal runout times) just after the appropriate transshipment(s). Secondly, TIE redistributes stock to match the ratio of average demand of each retailer to that of the whole retailer whenever there are retailers with less than desirable stock levels. Thirdly, another redistribution policy proposed by (Bertrand & Bookbinder, 1998) adjusted stock to achieve equal marginal cost over all retailers just before the replenishment period. This method has the disadvantage of not being able to respond to stockout before redistribution because the redistribution policy is only performed at the end of the replenishment period.

There are many other possible transshipment policies that can be devised based on the concept of TIE. For example, (Tagarus, 1999) compared two extreme policies, Random (RA) policy and Risk Balancing (RB) policy, which can be more or less easily implemented in practice. When one location faces a shortage, the decisions of the source location and the quantity of transshipment should take into account the risk of shortage in the following period.

The above mentioned policies have the disadvantage of not being able to respond to stockout before or after redistribution, and they cannot appropriately determine desired stock levels. (Lee et al., 2007) proposed a new lateral transshipment policy, service level adjustment (SLA), to effectively deal with retailer demand. The proposed policy can reduce risk by forecasting stockout in advance and efficiently responding actual stockout by combining TBA and TIE.

Recently, (Minner & Silver, 2005) observed that choosing the better of two extreme policies leads to performance that is nearly as good as a more complex analysis that takes account of the future impact of a transshipment on the cost at the location sending the shipment. These extreme policies under investigated are (i) never transship and (ii) always transship when there is a shortage at one location and stock available at another. They developed an analytical approach for estimating the expected cost. Thus, it provided a mechanism for selecting the better policy between these two extreme policies.

(Burton & Benerjee, 2005) examined the cost effects of two lateral (intra-echelon) transshipment approaches in a two-echelon supply chain network, with a single supply source at the higher echelon and multiple retail locations at the lower. Through a series of simulation experiments under different operating conditions, they found an ad hoc emergency transshipment approach appears to be significantly more effective in terms of several important criteria, as compared to a more systematic transshipment technique based on stock level equalization.

In view of the transshipment, most research has focused on determining when to fill transshipment requests from other dealers, ignoring the decision of determining when to send transshipment requests to other dealers. With an exception, (Zhao et al., 2006) developed optimal inventory transshipment policies that incorporate both types of decisions in a decentralized system. They devised threshold rationing and requesting levels for determining the optimal inventory and transshipment decisions for each individual dealer. They also considered a decentralized two-dealer network and use a game theoretic approach to characterize the equilibrium inventory strategies of the individual dealers. The research is classified based on transshipment policies are summarized in Table 1.

TBA(ELT)	TIE(PLT)	Combined or Newly developed
(Lee, 1987) (Axsäter, 1990) (Tagaras & Cohen, 1992) (Rudi et al., 2001)	(Gross, 1963) (Das, 1975) (Jonsson & Silver, 1987) (Bertrand & Bookbinder, 1998)	(Tagarus, 1999) (Lee et al., 2007) (Minner & Silver, 2005) (Burton & Benerjee, 2005) (Zhao et al., 2006)

Table 1. Transshipment policies

2.4 Inventory control policies in transshipment

Transshipment policies are incorporated with traditional inventory control policies which are classified based on two fundamental questions: when to replenish and how much to order. Commonly used inventory control policies such as (S-1,S), (Q,R), (R,S), and (s,S) will be discussed as follows.

Inventory control policy (S-1,S)

Continuous one-for-one stock replenishments (S-1,S) is a commonly used inventory control policy for a system in cooperation with transshipment. It means whenever any stock is withdrawn, a replenishment order is released. This control policy is especially suitable for slow-moving and expensive items. The first to deal with continuous one-for-one inventory policies in multi-echeon systems with transshipment were (Dada, 1984) and (Lee, 1987). One can refer to the following research for more in-depth description, (Lee, 1987), (Axsäter, 1990), (Sherbrooke, 1992), (Yanagi & Sasaki, 1992), (Alfredsson & Verrijdt, 1999), (Grahovac & Chakravarty, 2001), (Kukreja et al., 2001), and (Wong et al., 2002 & 2005).

(Lee, 1987) developed a method of determining the minimum cost inventory position for a system that allows transshipments between identical locations and finds approximations to measures of system performance including the expected number of backorders and transshipments. Expressions derived approximate the fractions of demands that can be satisfied by stock on hand, TBA, and backordering, and in doing so, proved that applying lateral transshipment reduces total cost.

Both (Axsäter, 1990) and (Sherbrooke, 1992) proposed similar approximations for systems that allow transshipments between non-identical locations. (Axsäter, 1990) analyzed a system similar to that of (Lee, 1987), but with the modification of assuming that warehouses within each group are not identical. Steady-state probability is derived by assuming exponentially distributed replenishment time. Analytical results were compared with simulation results to show that, in the case of non-identical warehouses, this proposed model gives better results.

Recently, (Grahovac & Chakravarty, 2001) formulated and solved the proposed model based on (S-1,S) policy. They reached some counter-intuitive conclusion that is saving is not always accompanied by a reduction in overall reduction inventory in the supply chain. These opposing trends suggest that new extra incentives are needed to enforce the transshipment arrangement. In addition, (Kukreja et al., 2001) developed a heuristic to determine replenishment and transshipment policies for a system with non-identical locations under the objective of minimizing cost.

(Wong et al., 2005) extended the single item model of (Wong et al., 2005) to a model of multiple items. They analyze a two-location, multi-item, continuous-review system for repairable items with one-for-one stock replenishments and determine policies for all items that minimize the total cost subject to a target level for average waiting time. However, these models are only appropriate for slow moving, expensive and/or repairable items.

Inventory control policy (Q,R)

The continuous (Q,R) policy consider a reorder quantity, reorder point (Q,R) system instead, where an order of fixed size (Q) is placed whenever the reorder point (R) is reached. The (Q,R) system is a very common and relatively straightforward system whose primary drawback is associated with demands of appreciable magnitude (Silver & Peterson, 1985). There are considerable amount of research on (Q,R) inventory control policy for system with transshipment. Readers can refer to the following research for more in-depth description, (Needham & Evers, 1998), (Evers, 2001), and recently (Xu et al., 2003), (Minner et al, 2003) and (Axsäter, 2003 a,b).

(Needham & Evers, 1998) examines the interaction of relevant costs and transshipment policies and presents a method for determining the point at which the benefits of transshipments outweigh their costs. Simulation and sensitivity analysis identify the relevant costs drivers and are used to construct a decision making tool for managers contemplating the implementation of transshipments. Simulation results indicate that the cost of a stockout is the primary determinant in the transshipment decision, with higher stockout cost levels generally increasing the likelihood that transshipment usage will lead to lower overall cost. A meta- model is proposed as a practical means of providing insight into when emergency transshipments should be employed.

Under (Q,R) continuous review policy, (Evers, 2001) and (Minner et al., 2003) developed heuristics to determine whether or not to make a transshipment in a multilocation inventory system facing a stockout. (Axsäter, 2003a) developed an approximate method of determining the replenishment policy for a continuous review multilocation inventory system in which a location facing a stockout sources items from locations with lower shortage costs whenever possible. In this paper, transshipments are only allowed in one direction, i.e., the flow of transshipment is in only one direction. Such policies can be of interest if the warehouses have very different shortage costs. Another interpretation is substitution in an inventory system. That is when a demand for a low quality item cannot be met directly, the item can be replaced by another high quality item. He provide a simple and efficient approximate technique for policy evaluation in such systems. Under the assumption that no further transshipment will take place, (Axsäter, 2003b) extends (Axsäter's, 2003a) modeled and proposed the decision rule and develop a heuristic to determine whether or not to make a transshipment in response to a stockout.

Inventory control policy (s, S)

Other studies of transshipment assume periodic review policies and they usually assume no order setup cost, so that an order-up-to or base-stock policy is appropriate. In a (s, S) inventory policy, an order is placed every time the inventory position drops to or below s, and the order size is the difference between S, the order up to level, and the inventory position at the time of placing the order. The outlets operate independently and follow a continuous review (s, S) inventory policy. In fact, the interactions in terms of transshipments make the system complex, and analytical results for such a system seem to be intractable. This type of inventory system with multiple locations interacting in terms of complete pooling of stock, and each location following a (s, S) type inventory control policy has not been dealt with in the past in the literature.

Some studies devised (s,S) inventory policy in transshipment such as (Krishnan & Rao, 1965), (Cantagalli, 1987), (Tagaras, 1989 & 1999), (Robinson, 1990), (Tagaras & Cohen, 1992), (Archibald et al., 1997), (Rudi et al., 2001), and (Herer et al., 2002). The scopes and contributions of these studies are discussed below.

The model of (Krishnan & Rao, 1965) minimized cost in a multilocation system with zero replenishment and transshipment lead times. (Cantagalli, 1987) evaluated the impact of four different emergency transshipment policies using the (s,S) inventory system. In the paper variant transshipment policies, complete pooling and partial pooling rules are examined. Though (s,S) systems are in use, they tend to be difficult to work with in terms of establishing the control parameters (Silver & Peterson, 1985). (Robinson, 1990) characterized the form of close-to-optimal policies for similar systems. (Tagaras & Cohen, 1992) examined a model with two locations and non-zero replenishment lead time. (Rudi et al., 2001) investigated the conflict between maximizing location and system profits in a two-location model. These models require a non-negligible lead time on the service of customer requests to allow the total demand to become apparent before transshipments are arranged. In highly competitive retail situations, such a delay would often lead to lost sales.

Moreover, (Herer et al., 2002) determined how much to replenish and how much to transship each period; thus this work can be viewed as a synthesis of transshipment problems in a static stochastic setting and multi-location dynamic deterministic lot sizing problems. They provide interesting structural properties of optimal policies which enhance our understanding of the important issues which motivate transshipments and allow us to develop an efficient polynomial time algorithm for obtaining the optimal strategy.

Recently, (Hu et al., 2005) adopted the major assumptions in (Krishnan & Rao, 1965) for an N-location inventory system but extended their one-period, base-stock inventory model to a multi-period, general (s, S)-type model. While (Robinson, 1990) considers the simultaneous determination of base stock inventory policies at each store as well as the transshipment decisions, they focus on the development of an appropriate (s,S)-type policy for a multi-location inventory system with centralized ordering. The focus of this research is to investigate the effect of transshipment costs on the optimal(s,S) ordering policy that minimizes inventory and transshipment costs. Then this (s,S) ordering policy is then compared with a simplified policy that assumes free and instantaneous transshipments. In general, the results indicated that using transshipments seem to be a very cost effective way of reducing inventories for situations with a large number of stores where transshipment costs are small relative to the stock-out plus holding costs.

Other studies assume periodic review policies and they usually assume no order setup cost, so that an order-up-to or base-stock policy is appropriate. Examples are (Gross, 1963), (Krishnan & Rao, 1965), (Das, 1975), (Hoadley & Heyman, 1977), (Cohen et al., 1986), (Tagaras, 1989 & 1999), (Robinson, 1990), (Tagaras & Cohen, 1992), (Archibald et al., 1997), (Rudi et al., 2001), and (Herer et al., 2002). Different from those examples, (Herer & Rashit, 1999) introduce the existence of non-negligible fixed and joint replenishment costs.

In sumarry, lateral transshipments have been analyzed from the perspective of both continuous time (e.g. Lee, 1987; Axsäter, 1990; Sherbrooke, 1992), as well as discrete periods (see, e.g. Showers, 1979; Archibald et al., 1997; Kochel, 1998). The relevant research is classified based on transshipment policies are summarized in Table 2.

(S-1,S)	(Q,R)	(R,S)	(s,S)
(Dada, 1984), (Lee, 1987). (Axsäter, 1990), (Sherbrooke, 1992), (Yanagi & Sasaki, 1992), (Alfredsson & Verrijdt, 1999), (Grahovac & Chakravarty, 2001), (Kukreja et al., 2001), (Wong et al., 2002 & 2005).	(Silver & Peterson, 1985), (Needham & Evers, 1998), (Evers, 2001), (Xu et al., 2003), (Minner et al, 2003), (Axsäter, 2003 a,b).	(Gross, 1963), (Krishnan & Rao, 1965), (Das, 1975), (Hoadley & Heyman, 1977), (Cohen et al., 1986), (Tagaras, 1989 & 1999), (Robinson, 1990), (Tagaras & Cohen, 1992), (Archibald et al., 1997), (Rudi et al., 2001), (Herer et al., 2002).	(Krishnan & Rao, 1965), (Cantagalli, 1987), (Tagaras, 1989 & 1999), (Robinson, 1990), (Tagaras & Cohen, 1992), (Archibald et al., 1997), (Rudi et al., 2001), (Herer et al., 2002), (Silver & Peterson, 1985), (Hu et al., 2005).

Table 2. Inventory control policies

2.5 Performance measures

As above mentioned, the implementation of supply chain management has significant impact on cost, service level, and quality. Emergency transshipments represent one way in which logistics managers can reduce inventories while simultaneously maintaining customer service levels. Therefore, the commonly used performance measures to evaluate the effectiveness of transshipment are the costs and service level. The relevant costs considered in the transshipment model are similar to those of inventory research. They are stockout cost (aka, shortage cost), holding cost, transportation cost and ordering cost. Stockout costs were used to assign a penalty when a customer request could not be filled. Two holding costs were classified as in-storage and in-transit, the in-transit holding cost is usually lower than the in-storage cost. Two transportation costs considered are routine and rush transportation costs. The routine transportation costs are taken from full-truckload (FTL) rates. Nevertheless, rush transportation costs are taken from less-than-truckload (LTL) rates. Ordering costs in the simulation model were accumulated each time an order was placed from either a retail center or a distribution center.

Some other papers addressed the transshipment problem with variant objectives. (Jönsson & Silver, 1987) examined a model in which the objective is to minimize backorders rather than cost. (Lee, 1987) developed a method of determining the minimum cost inventory position for a system that allows transshipments between identical locations and finds approximations to measures of system performance including the expected number of backorders and transshipments. (Bertrand & Bookbinder, 1998) considered this model with the objective of minimizing cost for the case of zero transshipment lead time. (Rudi et al., 2001) investigated the conflict between maximizing location and system profits in a two-location model.

(Lee et al., 2007) considered future demands, current stock quantity, and the degree of stockout, the service level proposed in their study can be used as criteria to evaluate the performance of lateral transshipment. It is called service level for the remaining period (SLRP) which is based on the concept of safety stock. Refer to (Lee et al., 2007), a summary of service levels from the previous research are shown in Table 3.

Cycle-service level (Lee & Larry, 2002)	the desirable probability of not occurring stockout in any cycle
Customer service level(Yan et al., 2003)	Portion of demand met
Customer service level (Biswas & Narahari, 2004)	Order fill rate: the fraction of demand are met from on-hand stock Probability of on-time delivery: the fraction of demand are met fulfilled timely
Service level (Surrie & Wagner, 2002)	(i) α -service level: the fraction of incoming order are fulfilled from on-hand stock (ii) β - service level: the proportion of incoming order quantity are fulfilled from on-hand stock (iii) γ - service level:1-mean demand not fulfilled /mean demand per period
Service level (Lee et al., 2007)	the probability of not occurring stockout for retailer during its remaining period RP

Table 3. Definitions of service level

3. Classifications of transshipment problems

One can think of the following important features that should be taken into account when trying to present existing research systematically: (1) the number of item(s) in inventory system, (2) the number of locations in the pooling group, (3) the number of warehouses/ supplier(s) (4) the replenishment lead time from the warehouse(s), (5) the demand process, (6) the timing of transshipment (preventive or emergency), (7) the measure of performance (cost or service level), (8) the storage space or waiting time constraint , (9) the direction of transshipment, and (10) the reparability of stocked items. Some have been addressed in the previous sections. Here just focus on the topics that have not been mentioned.

3.1 Number of item(s)

Most of the transshipment related research deals with single-item problems in which only one item at a time is considered. Such problems are typical when we use an item approach. Under an item approach, inventory levels for each individual item are set independently.

An alternative approach, denoted as the system approach by (Sherbrooke, 2004), considered all items in the system when making inventory-level decisions, and may lead to large reductions in inventory costs in comparison to an item approach. At present only a limited number of papers addressing lateral transshipments in the context of multi-item problems. (Archibald, 1997; Wong et al., 2005 & 2006).
(Archibald et al., 1997) considered a two-location, multi-item, multi-period, periodic review inventory system subject to a storage space limitation for all items. The demand is assumed to follow Poisson distribution and unlimited transshipments during a period in response to stockouts. (Wong et al., 2006) investigated a two-location, multi-item, continuous-review system for repairable items with one-for-one replenishments. The optimization problem is to determine stocking policies for all items that minimize the total system cost subject to a target level for the average waiting time for an arbitrary request for a ready-for-use part at each of the two locations. In their model, the decisions with respect to different items are coupled because of the multi-item service measure that is used. However, the solution procedure has a limitation since it requires a long computation time to solve rather large problems.
To overcome that limitation, (Wong et al., 2005) developed a simple and efficient solution procedure to obtain close-to-optimal solutions for the multi-item problem with lateral transshipments. The model is further extended to the case with multiple (and not limited to two) locations. Further, they also analyze the magnitude of the savings obtained by using the multi-item approach and lateral transshipments.

3. 2 Number of levels and locations in the system

Most of the previous study is focused on dealing with the transshipment problem in a two-echelon supply chain network, where it includes a single source supplier/warehouse at the higher level and multiple (two or more than two) retailers at the lower level. The assumptions for simple problem structure are necessary for the reason of computational tractability in the process of finding the optimal solution. Especially, the earlier study addressed relatively simple model with two stock outlets and/or one single period, thus limiting their practical application. To alleviate the loss of realism, the recent researchers have attempted heuristic approximation and/or simulation approaches in their analyses for the supply chain system with increased members.(for example, Robbinson, 1990; Dis & de kok, 1996; Needham & Evers, 1998; Tagaras, 1999; Chiou et al., 2007)
When lateral transshipment occurs only among the same level retailers, it is called intra-echelon. In contrast, transshipment can be conducted across different levels. For example, in case there are two or more suppliers/warehouses at the upper level, the retailers seek transshipment from other supplier/ warehouse when its designated supplier/warehouse can not fulfill its emergency delivery request. Therefore, the stock shipping operation for each retailer can be regular replenishment from its designated supplier, intra-echelon lateral transshipment, or inter-echelon transshipment from the supplier of the other region. Both (Needham & Evers, 1998) and (Chiou et al., 2007) considered allowing inter-transshipment across two levels.

3.3 Constraints: space, capacity, and time

Space, capacity, and time constraints are three factors that can affect significantly the system performance, either costs or service level. Not many works have been done in the areas of transshipment problem accounting for these factors. (Wong et al., 2006) investigated multi-item spare parts system, minimizing the total costs for inventory holding, lateral transshipments and emergency shipments subject to a target level for the average waiting time per demanded part at each of the two locations. In their model, the waiting time consideration is taken into account.

(Van Houtum & Zijm, 2000) classified inventory systems as two categories: service model and cost model. In a service model, the objective is to minimize the total system costs subject to a set of service level constraints, such as space, capacity, and time constraints. In a cost model, however, the service constraints are replaced with shortage penalty costs. Although in general the cost models are analytically more tractable, they have a serious limitation in that the penalty costs are generally hard to estimate. In this case, the service level constraints are constraints on the maximum expected waiting time. Hence they considered a service model rather than a cost model.

(Archibald et al., 1997) analyzed a multi-period, periodic-review model of a two-location inventory system in which lateral transshipments can occur at any time during the period. They formulated the two-location, single-item inventory problem as a Markov decision process and then extend the results to a two-location, multi-item inventory problem with limited storage space. In fact, this kind of optimization problem with space, capacity, and time constraints is appropriate to be analyzed by Lagrange relaxation (Porteus, 2002 and Wong et al., 2005). However, this problem is only a two-location problem It can be extended to a problem with multiple locations.

3.4 Transshipment direction

Transshipment direction is associated to the concepts of shortage cost differentiation and the usage of substitution item. Most previous papers focus on transshipments that are not limited to one direction. However, in some cases the decision makers also have to consider unidirectional transshipments (see e.g., Tagaras & Cohen, 1992; Axsäter, 2003; Liu & Lee, 2007). Especially, (Axsäter, 2003) presented a simple technique for evaluating policies with unidirectional transshipment. That is, such transshipment policy is only allowed in one direction. Such policy can be of interest if the warehouses have very different shortage costs. It may be irrational to tranship items from a warehouse with higher shortage cost to the warehouse with lower shortage cost. Another interpretation is substitution in an inventory system. When a demand for a low quality item cannot be met directly, the item can be replaced by another high quality item. The simulation study of their performance gives a good picture of how the considered lateral transshipments or substitutions affect the inventory system.

In contrast, (Liu & Lee, 2007) proposed Mokovian models for multi-item base-stock inventory policies where uni-directional substitutions are allowed among part types. They identified two substitution cases: substitution of incoming demand and substitution of backlogged demand for spare part management. As the number of part types increases, computational effort required to solve the Markovian models increases rapidly. In order to reduce computation burden, an approximation approach based on the decomposition of multi-dimensional state transition is developed for systems with two or more part types.

In addition, there are also a number of papers that consider substitution in inventory systems. (Bassok et al., 1999) provided exact results for a single-period Newsvendor type model. Various substitution models are also analyzed in e.g., (Pasternack & Drezner, 1991), (Bitran & Dasu, 1992), (Gerchak et al., 1996), (Hsu & Bassok, 1999).

4. Methodology

The methodologies adopted for investigating transshipment models can be divided into two classes: analytical and simulation.

4.1 Analytical approach

In (Wong et al., 2005a), considering the transshipment problem with waiting time constraints, the system behavior with respect to an item i is independent of all other items and may be described by a two-dimensional Markov process. This problem is appropriate to be analyzed by Lagrange relaxation which was applied to general constrained optimization problems.

(Kukreja & Schmidt, 2005) analyzed a model for lumpy demand parts in a multi-location inventory system with transshipment by using analytical and simulation techniques. They derived analytical results for the mean and variance of the lead-time demand at various locations and then use simulation methodology to determine inventory control policies for such a system. In particular, when the demand can not be met fully from the location's on-hand stock, a dynamic programming recursion was used to and the lowest transshipment cost solution for satisfying demand at the location.

In (Wong et al., 2006), an integer-programming problem with a nonlinear objective function and non-linear constraints was structured for multi-item multi-location spare parts systems with lateral transshipment and waiting time constraints. Four different heuristics were developed and evaluated in terms of their total costs and computation times. The results showed that the greedy-type heuristic has the best performance.

In (Archibald, 2006), for a given replenishment decision, the problem of minimizing the long run average cost per period was modeled as a Markov decision process. The state of the system is the stock level in each of the locations at a review epoch. The decision is the number of items to order for each location. Due to the storage limit at the locations, the number of states and decisions are finite. Therefore, the problem is an infinite horizon, average cost Markov decision process with finite state and action spaces (see e.g., Puterman, 1994).

New approaches such as the game theory approach for solving the transshipment problem have drawn attention from researchers. For example, (Reyes, 2005) solved the transshipment problem for maintaining stable conditions in the logistics network by using the well-known Shapley value concept from cooperative game theory.

4.2 Simulation approach

Due to the complexities involved in the analytical modeling and solution of multi-echelon supply chain problems, some researchers have attempted heuristic approximations and/or simulation approaches, in efforts to maintain at least some degree of realism in their analyses.

(Needham & Evers, 1998) investigated the interaction of relevant costs and transshipment policies via simulation study and presented a method for determining a threshold value at which the benefits of transshipments outweigh their costs. They found that the cost of a stockout is the primary determinant in the transshipment decision, with lower stockout cost levels generally decreasing the likelihood that transshipment usage. A meta-model was also proposed as a practical means of providing insight into when emergency transshipments should be employed.

(Ozdemir et al., 2006) analyzed a capacitated transshipment problem. They modeled it as network flow problem embedded in a stochastic optimization problem. They tackled the problem by proposing a solution procedures based on infinitesimal perturbation analysis (IPA). IPA is an efficient simulation-based optimization technique (Ho. et al., 1979). IPA-based methods have also been introduced to analyze supply chain problems (Glasserman & Tayur, 1995; Here et al., 2006). With IPA, the idea is to use the expected value of the sample path derivative obtained via simulation, instead of using the derivative of the expected cost, in a gradient search algorithm to update the order- up-to level for each stock location.

(Gong & Yucesan, 2006) utilized simulation optimization by combining an LP/Network flow in corporate with infinitesimal perturbation analysis (IPA) to analyze the problem, and obtained the optimal base stock quantities through sample path optimization.

(Zhao & Sen, 2006) conducted a comparison of sample-path based simulation and stochastic decomposition for multi-location transshipment problems proposed by (Herer et al., 2006), considering one supplier, and *N* non-identical retailers who face uncertain customer demands. Each retailer reviews its own inventory periodically, and replenishes its stock by placing orders with the supplier. They investigated the performance of two methods: infinitesimal perturbation analysis with Stochastic Quasi Gradient (IPA/SQG) and Random Stochastic Decomposition (RSD). The computational results showed that while IPA/SQG and RSD methods provide solutions of similar quality, the amount of computational time required by RSD is significantly lower because it takes advantage of the special structure of the two-stage stochastic linear program.

5. Conclusion and directions for further research

The list of research papers dealing with transshipments to date is quite long and no attempt is made here to exhaust it. In this chapter we mainly focus on presenting a comprehensive description, classification, methodologies and solution procedures, and research directions for further study of transshipment in supply chain system.

In view of the transshipment problems in a supply chain system, they can be characterized by four considerations: basic assumptions, transshipment policies, inventory control policies, and performance measurement. We further discuss the transshipment problem based on the features such as: the number of item(s) in inventory system, the number of locations in the pooling group; the storage space or waiting time constraint, and the direction of transshipment. Next, some literatures are discussed and classified into two methodologies of solution procedures, analytical and simulation. In this paper, we attempt to increase the understanding of the properties, characteristics, and methodologies of transshipment problem. Although numerous researches have contributed in this area, the investigated structure is much simpler than the practical. There still exits rich research opportunities for considering more complex systems with more echelons, items and locations. Some extensions are pointed out as follows.

The transshipment directions in two-location groups are much easier to specify than those of larger groups with more locations. Some alternative transshipment policies and priority rules are taken into account when there are multiple potential senders or receivers for each

transshipment request. In addition, the source of the transshipment system may be more than one in practice. There are multiple sources supplying to multiple warehouses, and each warehouse supplies a group of retailers. While the transshipment can be made across different echelon, not only at the same level, the transshipment sequence options and complexity of the network system increases significantly.
The effectives of a wider range of cost parameters and other methods of inventory control besides continuous review policies (S-1, S), (Q, R) and periodic review policies (s, S) need still further investigation.
Non-negligible trans-shipment times and the timing of transshipment incorporation with different inventory control policies are interesting topics for further research.
The space limit and the capacitated sources those considerations reflect more practical situation are also needed further study. Therefore, there still exists rich opportunity for further research in this topic.
The transshipment problem can be in corporate with vertical emergency shipment from two or more sources. Such policies combine inter-echelon emergency shipment and intra-echelon transshipment. In summary, there exist rich research opportunities in the areas of transshipment for supply chain systems.

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22

The Feasibility Analysis of Available-to-Promise in Supply-Chain System under Fuzzy Environment

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1. Introduction

Today enterprises face many rigorous competitive market pressures and challenges, including the globalization of competition and cooperation, a variety of customer requirements and shortened product-life cycles. An enterprise has to seek effective methods to adjust the management strategy and to sustain competitive advantage. For example, Material Requirement Planning (MRP), Manufacturing Resource Planning (MRPII) and Enterprise Resource Planning (ERP) (Enns, 2002; Min & Zhou, 2002) are used to integrate the operation processes and resources for enterprises. The purpose of these tools is to reduce the response time to meet the market demand and increase customer satisfaction.

As the Internet and information technology grow rapidly, the industrial environment becomes more competitive for individual enterprises. In the global marketplace, no longer do individual enterprises compete as an independent entity but rather as an integral part of the supply chain (Enns, 2002). In other words, each enterprise will depend on its management ability to integrate and coordinate the complicated network of business relationships among supply-chain members (Cooper & Lambert, 2000). Therefore, supply-chain management (SCM) has become one of the most important issues for enterprises.

A supply chain may be viewed as an integrated system that performs the procurement of raw material, its transformation to intermediate and end-products, distributor and promoting of the end-products to either retailers or customers (Cooper & Lambert, 2000; Min & Zhou, 2002). In recent years, many researchers have become very interested in supply-chain management problems and the concepts of SCM from different viewpoints which have been presented (Christopher et al., 1998; Cooper & Lambert, 2000; Lee et al., 1997; Ross, 1997; Richard et al., 2003). Unfortunately, there is no explicit description of supply-chain management or its activities in the literature (Tan, 2001). For example, New and Payne (1995) described supply-chain management as the chain linking each element of the manufacturing and supply processes from raw materials to the end user, encompassing several organizational boundaries. Jukka et al., (2001) described supply-chain management as a new way to provide goods and services to the end-customer at the lowest cost and highest service level, for which centric approach to managing the supply chain is no longer appropriate. SCM is an integrated approach to increase the effectiveness of the logistics chain by improving cooperation between members in the chain. Figure 1 shows that the activities of a supply chain are comprised of two fundamental procedures: (1) the production layout and inventory control process, and (2) the distribution and logistics process (Beamon, 1998).

There is a growing interest in exploiting supply-chain models in real applications and in developing decision-support systems to enhance supply-chain management and control. However, a real supply chain operates in an uncertain environment. Different sources and types of uncertainty exist along the supply chain and these make supply-chain management problems more complex (Lee et al., 1997; Dejonckheere et al., 2002; Dolgui & Ould-Louly, 2002; Ouyang & Chang, 2002). In general, the supply-chain system is essential to provide the precise commitment of customers, promise the customers to deliver on time, and maintain the requirement of product and service quality. Facing the dynamic states of the external market, however, the various operation times are not easy to determine in real supply chains. Therefore, the enterprise cannot always fulfill the exact promised time for customers. In general, decreasing the inventory and shortening the operation time are the two main criteria for evaluating the performance and resolving the uncertainty problems in a supply-chain system (Petrovic et al., 1998; Petrovic, 2001). The operation time includes the time necessary for order processing, the production time and/or the transportation time. Traditionally, uncertain parameters in operation-time problems have been modeled by probability distributions in the literature (Mon et. al., 1995; Dolgui & Ould-Louly, 2002; Stevenson, 2002; Fatemi Ghomi & Rabbani, 2003; Dubois et. al., 2003). However, uncertain parameters can only be specified using the experience and subjective judgment of managers. The standard probabilistic reasoning methods are not appropriate to deal with this type of uncertainty problem (Petrovic et al., 1998; Petrovic, 2001). Therefore, in order to deal with the various uncertainties in operation time and the subjective judgment of decision makers, triangular fuzzy numbers will be used to express the lead-time for each member of the supply chain. Considering these uncertainties in operation time, we propose an order fulfillment analysis model for a supply-chain system by combining fuzzy-set theory with program evaluation and review technique (PERT).

Program evaluation and review technique (PERT) (Chen & Chang, 2001; Dubois et al., 2003; Fatemi Ghomi & Rabbani, 2003) is the most widely used management technique for planning and coordinating large-scale projects. By using PERT, managers are able to obtain (Stevenson, 2002):

(1) a graphical display of project activities,
(2) an estimate of how long the project will take,
(3) an indication of which activities are the most critical to timely project completion,
(4) an indication of how long any activity can be delayed without delaying the project.

Therefore, PERT is suitable for computing the order-completion time and forecasting the order-fulfillment ability in the supply-chain system. In traditional program evaluation and review techniques, various dynamic activity durations must be a crisp number or obedient to a certain probability distributions which usually are of Beta type. In PERT, we must specify an optimistic time, a most probable (or most likely) time, and a pessimistic time to estimate the duration of each activity. Optimistic time is the “best” activity completion time that could be obtained in a PERT network. Probable time is the most likely time to complete an activity in a PERT network. Pessimistic time is the “worst” activity time that could be expected in a PERT network. The three times are used to calculate an expected completion time and variance for each activity (Dawson & Dawson, 1995 1998; Premachandrak, 2001). However, precise information about the durations of activities is seldom available in some contexts, like the early rough planning of long range projects.

In a real situation, the operation time of each activity is usually difficult to define and estimate. This implies that the activity time may be ill defined. Therefore, in recent years many researchers have developed the fuzzy PERT (FPERT) by combining the concepts of fuzzy-set theory with PERT to solve the project planning and control problem (Chen & Chang, 2001; Dubois et al., 2003; Fatemi Ghomi & Rabbani, 2003; Hapke & Sloinski, 1994; Hapke & Sloinski, 1996; Kuchta, 2001, Mon et al., 1995; Fatemi Ghomi & Teimouri, 2002). In FPERT, a fuzzy number can be used to express the duration time of each activity. The fuzzy PERT was first presented by Chanas & Kamburowski (1981). They use the fuzzy numbers to express the durations of all activities in project network. Based on the given possibility distributions of activity durations, the possibility distribution of the project completion time can be derived. In fact, the three time estimates are used to express the fuzzy duration of all activities in their method. And then, the α-cut of fuzzy number is applied to calculate the interval of completion time of project network. However, it can obtain the different intervals of completion time with different α values. Under this condition, we cannot indicate the critical activities and paths effectively in a project network. Mon et al., (1995) assume that the duration of each activity is positive fuzzy number. Using the α-cut of each fuzzy duration, the interval is denoted by $\widetilde{A}^{\alpha} = [a_L^{\alpha}, a_R^{\alpha}]$. In this interval, a_L^{α} is the lower bound of duration and a_R^{α} is the upper bound of duration. Applying the linear combination of $\widetilde{A}^{\alpha}$ to represent the operation time of each activity and determine the critical activities and paths. However, this approach will find the different critical activities and paths in accordance with α values. Chanas % Zielinski (2001) assume that the operation time of each activity can be represented as crisp, interval or fuzzy number. The operation procedure of this method like as the method of Mon et al., (1995). Dubois et al., (2003) indicated that each activity has different importance on a critical path. Therefore, they proposed a method to calculate the importance degree of each activity and path when choice a set of activities randomly. In these fuzzy PERT methods, fuzzy numbers are used to express the operation times of activities to reduce the uncertainties. However, these fuzzy PERT methods are complicated for calculating the critical degrees of each activity and path. Additionally, these methods cannot compute the possibility of meeting a certain requirement time effectively and easily.

For a supply-chain network, the most important issue for manager is to compute the fulfillment degree effectively when the due-date is given by customer. Therefore, in this paper, a revised FPERT method is proposed to calculate the fuzzy completion time and identify the fulfillment degree for the supply-chain system. In the calculation process, the generalized mean-values method (Lee & Li, 1988) is applied to rank the fuzzy operation times and determine the critical members of the supply chain. Then, an available-to-promise (ATP) index is defined by comparing the fuzzy completion time and required due date of the customer. According to the ATP value, the order fulfillment ability of a supply-chain system can be quickly identified in specific market conditions.

In this chapter, a revised FPERT method is applied to a cycle-time management problem in a supply-chain system. First, the fuzzy completion time of the supply-chain system is calculated with the Fuzzy PERT method. Second, the critical degrees of members and paths of the supply-chain system are identified in accordance with the fuzzy float time of members. Next, the index of available-to-promise (ATP) is defined and calculated to indicate the order-fulfillment degree of the supply-chain system. Finally, a simulation analysis is presented to illustrate the procedures for our proposed method at the end of this paper.

2. Fuzzy sets and notations

A fuzzy set can be defined mathematically by assigning to each possible element in the universe of discourse a value representing its grade of membership in the fuzzy set (Zadeh, 1965). This grade corresponds to the degree to which that element is similar to the concept represented by the fuzzy set. Thus, elements may belong in the fuzzy set to a greater or lesser degree as indicated by a larger or smaller membership grade. As already mentioned, these membership grades are very often represented by real number values ranging in the closed interval between 0 and 1 (Klir & Yuan, 1995).

2.1 Fuzzy number

The fuzzy number $\tilde{A}$ is a fuzzy set whose membership function $\mu_{\tilde{A}}(x)$ satisfies the following conditions (Klir & Yuan, 1995):

(1) $\mu_{\tilde{A}}(x)$ is piecewise continuous;

(2) $\mu_{\tilde{A}}(x)$ is a convex fuzzy subset;

(3) $\mu_{\tilde{A}}(x)$ is normality of a fuzzy subset. It implies that at least one element x_0 must have a membership grade of 1 for the fuzzy set, i.e., $\mu_{\tilde{A}}(x_0)=1$.

2.2 The α -cut of fuzzy number

The α-cut of fuzzy number $\tilde{A}$ is defined as

$$\tilde{A}^{\alpha}=\{x_i : \mu_{\tilde{\mathrm{A}}}(x_i)\geq \alpha, x_i \in \mathrm{X}\} \tag{1}$$

where $\alpha \in [0,1]$.

The symbol $\tilde{A}^{\alpha}$ represents a non-empty bounded interval contained in X, which can be denoted by $\tilde{\mathrm{A}}^{\alpha}=[a_L^{\alpha}, a_R^{\alpha}]$, a_L^{α} and a_R^{α}, the lower and upper bounds of the closed interval, respectively (Kaufmann & Gupta, 1991; Zimmerman, 1991).

Give any two positive fuzzy numbers $\tilde{\mathrm{m}}$, $\tilde{\mathrm{n}}$ and a positive real number r, the α-cut of two fuzzy numbers are $\tilde{\mathrm{m}}^{\alpha}=[m_l^{\alpha}, m_u^{\alpha}]$ and $\tilde{\mathrm{n}}^{\alpha}=[n_l^{\alpha}, n_u^{\alpha}]$ ($\alpha \in [0,1]$), respectively. According to the interval of confidence (Kaufmann & Gupta, 1991), some main operations of positive fuzzy numbers $\tilde{\mathrm{m}}$ and $\tilde{\mathrm{n}}$ can be expressed as follows:

$$(\tilde{m} \oplus \tilde{n})^{\alpha} = [m_l^{\alpha} + n_l^{\alpha}, m_u^{\alpha} + n_u^{\alpha}], \tag{2}$$

$$(\tilde{m} \Theta \tilde{n})^{\alpha} = [m_l^{\alpha} - n_u^{\alpha}, m_u^{\alpha} - n_l^{\alpha}], \tag{3}$$

where $\oplus$ and Θ are fuzzy additive and subtractive operators, respectively.

2.3 Triangular Fuzzy Number (TFN)

A triangular fuzzy number is a popular type of fuzzy number, which can be expressed as $\tilde{T} = (l, m, u)$. When $l > 0$, then $\tilde{T}$ is a positive triangular fuzzy number (PTFN) (Dubois & Prade, 1980; Zimmerman, 1991). The membership function of positive triangular fuzzy number $\tilde{T}$ (shown in Figure 2) is defined as:

$$\mu_{\tilde{T}}(x) = \begin{cases} \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & otherwise \end{cases} \tag{4}$$

where $l > 0$.

When given two positive triangular fuzzy numbers $\tilde{T}_1 = (l_1, m_1, u_1)$ and $\tilde{T}_2 = (l_2, m_2, u_2)$, the additive ($\oplus$) and subtractive ($\Theta$) operations between them can be expressed as follows (Kaufmann & Gupta, 1991):

$$\tilde{T}_1 \oplus \tilde{T}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{5}$$

$$\tilde{T}_1 \Theta \tilde{T}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{6}$$

2.4 Ranking method for fuzzy numbers

Many ranking methods have been developed to transform fuzzy numbers into crisp values (Chen & Hwang, 1992; Nicole et al., 2002). Lee & Li (1988) presented the so-called generalized mean value method. It is very easy to compare fuzzy numbers with this method. Let $\tilde{T} = (l, m, u)$ be a triangular fuzzy number whose defuzzied value is easily computed (Lee & Li, 1988) as

$$G(\tilde{T}) = \frac{l+m+u}{3} \tag{7}$$

and

$$S(\widetilde{T}) = \frac{1}{18}[l^2 + m^2 + n^2 - lm - \ln - mn] \tag{8}$$

where $G(\widetilde{T})$ is the generalized mean value and $S(\widetilde{T})$ is the deviation of fuzzy number $\widetilde{T}$, respectively.

Suppose $\widetilde{T}_1 = (l_1, m_1, u_1)$ and $\widetilde{T}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers. If $G(T_1) > G(T_2)$, then $\widetilde{T}_1 > \widetilde{T}_2$; if $G(T_1) = G(T_2)$ and $S(\widetilde{T}_1) < S(\widetilde{T}_2)$, then $\widetilde{T}_1 > \widetilde{T}_2$; if $G(T_1) = G(T_2)$ and $S(\widetilde{T}_1) = S(\widetilde{T}_2)$, then $\widetilde{T}_1 \approx \widetilde{T}_2$.

3. Fuzzy PERT

Because the durations of activities in supply-chain network are usually difficult to estimate and determine exactly, it is reasonable way to use the fuzzy numbers to describe the durations. Therefore, positive triangular fuzzy numbers are used in this paper to express the operation time of each activity (member) on the supply-chain network. In general, there are two conventions for constructing a network graph. These conventions are referred to as activity-on-arrow (AOA) and activity-on-node (AON) (Stevenson, 2002). Both conventions are illustrated in Figures 3 and 4. In this paper, an activity-on-node (AON) graph is adopted to represent a project network. This graph includes two virtual activities of null duration, the initial node (I) and the ending node (E). According to the computation procedure of PERT, the forward pass is performed to calculate the fuzzy earliest-start-time and fuzzy earliest-finish-time as

$$\widetilde{S}_i^e = \max_{j \in P(i)} \{\widetilde{S}_j^e \oplus \widetilde{d}_j\} \tag{9}$$

$$\widetilde{F}_i^e = \widetilde{S}_i^e \oplus \widetilde{d}_i \tag{10}$$

where

$\widetilde{S}_i^e$ is the fuzzy earliest-start-time of activity i and $\widetilde{F}_i^e$ is the fuzzy earliest-finish-time of activity i. If i=I, then $\widetilde{S}_I^e = (0,0,0)$. If $i = E$, then $\widetilde{F}_E^e = \widetilde{T}_{end}$. $\widetilde{T}_{end}$ is the fuzzy completion time of supply-chain network. $P(i)$ is the set of predecessors of activity i. $\widetilde{S}_j^e$ is the fuzzy earliest-start-time of activity j. $\widetilde{d}_j$ is the fuzzy operation time of activity j. $\widetilde{d}_i$ is the fuzzy operation time of activity i.

The backward pass is performed to calculate the fuzzy latest-start-time and fuzzy latest-finish-time as

$$\widetilde{F}_i^l = \min_{j \in S(i)} \{\widetilde{F}_j^l \Theta \widetilde{d}_j\} \tag{11}$$

$$\widetilde{S}_i^{\,l} = \widetilde{F}_i^{\,l} \Theta \widetilde{d}_i \tag{12}$$

where

$\widetilde{F}_i^{\,l}$ is the fuzzy latest-finish-time and $\widetilde{S}_i^{\,l}$ is the fuzzy latest-start-time of activity i.

In the FPERT process, the generalized mean method (Lee & Li, 1988) is applied to compare the fuzzy numbers, and identify $\widetilde{S}_i^{\,e}$, $\widetilde{S}_i^{\,l}$, $\widetilde{F}_i^{\,e}$ and $\widetilde{F}_i^{\,l}$ of each activity i.

In traditional PERT the float time (slack time) of each activity is difference between latest start time and earliest start time, or difference between latest finish time and earliest finish time (Stevenson, 2002). According to the $\widetilde{S}_i^{\,e}$, $\widetilde{S}_i^{\,l}$, $\widetilde{F}_i^{\,e}$ and $\widetilde{F}_i^{\,l}$ of each activity i, the fuzzy float time can be calculated as

$$\widetilde{m}_i = \widetilde{S}_i^{\,l} \Theta \widetilde{S}_i^{\,e} \tag{13}$$

or

$$\widetilde{m}_i = \widetilde{F}_i^{\,l} \Theta \widetilde{F}_i^{\,e} \tag{14}$$

where

$\widetilde{m}_i$ is the fuzzy float time of activity i.

$\widetilde{S}_i^{\,l}$ is the fuzzy latest-start-time of activity i.

$\widetilde{S}_i^{\,e}$ is the fuzzy earliest-start-time of activity i.

$\widetilde{F}_i^{\,l}$ is the fuzzy latest-finish-time of activity i.

$\widetilde{F}_i^{\,e}$ is the fuzzy earliest-finish-time of activity i.

Property:

According to the definition of $\widetilde{S}_i^{\,e}$, $\widetilde{S}_i^{\,l}$, $\widetilde{F}_i^{\,e}$ and $\widetilde{F}_i^{\,l}$, we know that the Equations (13) and (14) are identical.

Proof:

Suppose that the $\alpha - cut$ of $\widetilde{S}_i^{\,e}$, $\widetilde{S}_i^{\,l}$, $\widetilde{F}_i^{\,e}$, $\widetilde{F}_i^{\,l}$, and $\widetilde{d}_i$ for activity i can be represented as

$$\widetilde{S}_i^{\,e^\alpha} = [s_{i\ L}^{e^\alpha}, s_{i\ R}^{e^\alpha}],$$

$$\widetilde{S}_i^{\,l^\alpha} = [s_{i\ L}^{l^\alpha}, s_{i\ R}^{l^\alpha}],$$

$$\widetilde{F}_i^{\,e^\alpha} = [f_{i\ L}^{e^\alpha}, f_{i\ R}^{e^\alpha}],$$

$$\widetilde{F}_i^{l\alpha} = [f_{iL}^{l\alpha}, f_{iR}^{l\alpha}],$$

$$\widetilde{d}_i^{\alpha} = [d_{iL}^{\alpha}, d_{iR}^{\alpha}]$$

for $\alpha \in [0, 1]$.

According to the Equations (10) and (12), we know that $\widetilde{F}_i^{e\alpha} = \widetilde{S}_i^{e\alpha} \oplus \widetilde{d}_i^{\alpha}$ and $\widetilde{S}_i^{l\alpha} = \widetilde{f}_i^{l\alpha} \Theta \widetilde{d}_i^{\alpha}$. Then, we have

$$[f_{iL}^{e\alpha}, f_{iR}^{e\alpha}] = [s_{iL}^{e\alpha}, s_{iR}^{e\alpha}] \oplus [d_{iL}^{\alpha}, d_{iR}^{\alpha}] = [s_{iL}^{e\alpha} + d_{iL}^{\alpha}, s_{iR}^{e\alpha} + d_{iR}^{\alpha}]$$

and

$$[s_{iL}^{l\alpha}, s_{iR}^{l\alpha}] = [f_{iL}^{l\alpha}, f_{iR}^{l\alpha}] \Theta [d_{iL}^{\alpha}, d_{iR}^{\alpha}] = [f_{iL}^{l\alpha} - d_{iR}^{\alpha}, f_{iR}^{l\alpha} - d_{iL}^{\alpha}]$$

It implies that

$$f_{iL}^{e\alpha} = s_{iL}^{e\alpha} + d_{iL}^{\alpha}, \quad f_{iR}^{e\alpha} = s_{iR}^{e\alpha} + d_{iR}^{\alpha}, \; s_{iL}^{l\alpha} = f_{iL}^{l\alpha} - d_{iR}^{\alpha}, \; s_{iR}^{l\alpha} = f_{iR}^{l\alpha} - d_{iL}^{\alpha}.$$

Then,

$$f_{iL}^{e\alpha} + s_{iR}^{l\alpha} = s_{iL}^{e\alpha} + f_{iR}^{l\alpha}$$

$$s_{iL}^{l\alpha} + f_{iR}^{e\alpha} = f_{iL}^{l\alpha} + s_{iR}^{e\alpha}$$

It implies that

$$s_{iR}^{l\alpha} - s_{iL}^{e\alpha} = f_{iR}^{l\alpha} - f_{iL}^{e\alpha}$$

$$s_{iL}^{l\alpha} - s_{iR}^{e\alpha} = f_{iL}^{l\alpha} - f_{iR}^{e\alpha}$$

According to the definition of fuzzy float time, we have

$$\begin{aligned}
\widetilde{m}_i^{\alpha} &= (\widetilde{s}_i^{l} \Theta \widetilde{s}_i^{e})^{\alpha} \\
&= [s_{iL}^{l\alpha}, s_{iR}^{l\alpha}] \Theta [s_{iL}^{e\alpha}, s_{iR}^{e\alpha}] \\
&= [s_{iL}^{l\alpha} - s_{iR}^{e\alpha}, s_{iR}^{l\alpha} - s_{iL}^{e\alpha}] \\
&= [f_{iL}^{l\alpha} - f_{iR}^{e\alpha}, f_{iR}^{l\alpha} - f_{iL}^{e\alpha}] \\
&= [f_{iL}^{l\alpha}, f_{iR}^{l\alpha}] \Theta [f_{iL}^{e\alpha}, f_{iR}^{e\alpha}] \\
&= (\widetilde{F}_i^{l} \Theta \widetilde{F}_i^{e})^{\alpha}
\end{aligned}$$

for $\alpha \in [0, 1]$.

Therefore, one can prove that the Equations (13) and (14) are identical for the fuzzy float time of each activity in a supply-chain network.

In traditional PERT, activity i is called a critical activity if its float time is zero. In general, the fuzzy float time is smaller; the degree of criticality is higher for each activity. Suppose that the fuzzy float time of activity i is denoted by $\widetilde{m}_i = (a_i, b_i, c_i)$, and then the degree of criticality can be defined as

$$CD_i = \begin{cases} 1, & \text{if } b_i \le 0 \\ \mu_{\widetilde{m}_i}(0), & \text{if } b_i > 0 \end{cases} \tag{15}$$

where

CD_i is the critical degree of activity i.

$\mu_{\widetilde{m}_i}(0)$ is the membership degree of zero belongs to the fuzzy float time.

In a supply network, a path is a sequence of activities that leads from the initial node to the ending node. According to the critical degree of each activity, the degree of criticality of a path can be calculated as

$$\pi(P_k) = \min_{i \in P_k} \{CD_i\} \tag{16}$$

where P_k is the k-th path in the network and $\pi(P_k)$ is the critical degree of k-th path.

If the path P is critical path, then $\pi(P)$ must satisfy that $\pi(P) = \max_k \pi\{P_k\}$.

4. Order-fulfillment analysis model

Suppose that there are certain suppliers, manufacturers, distributors and final retailers in a supply chain. The operation time from receiving the order to delivering the materials to the manufacturer or suppliers S_i $(i = 1,2,...,m)$ is denoted by $\widetilde{d}_{S_i} = (S_{i1}, S_{i2}, S_{i3})$; the operation of the production of manufacturer M_k is denoted by $\widetilde{d}_{M_i} = (M_{i1}, M_{i2}, M_{i3})$; the operation time of the assembly and distributor is denoted by $\widetilde{d}_{D_i} = (D_{i1}, D_{i2}, D_{i3})$; the operation time of the final retailer is denoted by $\widetilde{d}_{R_i} = (R_{i1}, R_{i2}, R_{i3})$.

Two basic possible cases in the supply-chain system are discussed below:

(1) One supplier delivers materials to one manufacturer; one manufacturer delivers products to one distributor, who sends the products to the final retailer (shown in Figure 5). In this case, the completion time ($\widetilde{T}_{end}$) of the supply-chain system can be computed as:

$$\widetilde{T}_{end} = \widetilde{d}_S \oplus \widetilde{d}_M \oplus \widetilde{d}_D \oplus \widetilde{d}_R \tag{17}$$

(2) Several suppliers deliver materials to one manufacturer, one manufacturer delivers products to one distributor, who sends the products to the final retail (shown in Figure

6). In this case, the completion time ($\widetilde{T}_{end}$) of the supply-chain system may be computed as

$$\widetilde{T}_{end} = \max\{\widetilde{d}_{S_i}, \widetilde{d}_{S_j}\} \oplus \widetilde{d}_M \oplus \widetilde{d}_D \oplus \widetilde{d}_R \tag{18}$$

An actual supply-chain network may consist of two graphs of cases 1 and 2. Suppose the requirement due-date (RDD) of the customer is denoted by $\widetilde{R}$ and the completion time (CT) of the supply-chain system is denoted by $\widetilde{T}_{end}$. If $RDD \geq CT$, then the supply-chain system can satisfy the requirement of the customer completely. However, it is difficult to make a comparison between RDD and CT directly when they are fuzzy numbers. Let $\widetilde{R} = (r_1, r_2, r_3)$ and $\widetilde{T}_{end} = (e_1, e_2, e_3)$, then $\widetilde{R}\Theta\widetilde{T}_{end} = (r_1 - e_3, r_2 - e_2, r_3 - e_1)$. The membership function of fuzzy number $\widetilde{R}\Theta\widetilde{T}_{end}$ is shown in Figure 7. Therefore, the order-fulfillment ability analysis of the supply-chain system is described as follows:

(1) If $r_1 - e_3 \geq 0$, then the order-fulfillment degree is 100%.

(2) If $r_3 - e_1 \leq 0$, then the order-fulfillment degree is zero. In other words, the supply-chain system cannot deliver on time.

(3) If $r_1 - e_3 < 0 < r_3 - e_1$, then the order-fulfillment degree is denoted by the available-to-promise (ATP). The available-to-promise (ATP) can be defined as

$$ATP = \begin{cases} 1 \quad , \quad r_1 - e_3 \geq 0 \\ \dfrac{\delta_1}{\delta_1 + \delta_2} \quad , \quad r_1 - e_3 \leq 0 \leq r_3 - e_1 \\ 0 \quad , \quad r_3 - e_1 \leq 0 \end{cases} \tag{19}$$

where

$\delta_1 = \int_0^\infty \mu_{\widetilde{R}\Theta\widetilde{T}_{end}}(x)dx$, $\delta_2 = \int_{-\infty}^0 \mu_{\widetilde{R}\Theta\widetilde{T}_{end}}(x)dx$ and $\mu_{\widetilde{R}\Theta\widetilde{T}_{end}}(x)$ is the membership function of fuzzy number $\widetilde{R}\Theta\widetilde{T}_{end}$.

In other words, when the value δ_1 is larger, the degree of order-fulfillment in the supply-chain system is higher. Consequently, the supply-chain system is more flexible. It implies that the supply-chain system can respond faster to meet the requirements of the customer.

In a supply-chain network, if the critical degrees of two activities (members) i and j are identical and $CD_i = CD_j = 1$ then the generalized mean method (Lee & Li, 1988) can be used to determine the priority to shorten the duration and increase ATP value. The generalized mean value is smaller; the priority is higher to shorten the duration.

5. Analysis of simulation

In this paper, the following assumptions have made in the supply-chain network.

(1) The production facilities have unlimited capacities.
(2) Customer demand is confined to a single product.
(3) The raw material inventory is supplied from an external source.
(4) External demand is fulfilled from the end-product inventory.

In order to implement the simulation analysis, the structure of the supply-chain system is assumed to be as shown in Figure 8. In Figure 8, S_1 and S_2 indicate two suppliers; M_1, M_2 and M_3 indicate three manufacturers; D_1, D_2 and D_3 indicate three distributors; R_1 indicates the final retailer. Furthermore, the operation times of the suppliers, the manufacturers, the distributor and the retailer are expressed by triangular fuzzy numbers as shown in Table 1. According to the fuzzy PERT algorithm, the completion time of the supply-chain network is computed as $\widetilde{T}_{end} = (13, 18, 25)$. According to the computation process of proposed method, one can calculate the fuzzy earliest-start-time, fuzzy earliest-final-time, fuzzy latest-start-time and fuzzy latest-final-time and fuzzy float time of each activity (shown as Table 1). The critical degree of each activity can be computed based on the fuzzy float time. For example, the degree of criticality of 2nd supplier (S_2) is denoted by $CD_2 = 1$. The critical degree of each path of supply-chain network is shown in Table 2. According to Tables 1 and 2, the critical members are S_2, M_2, D_2, D_3, and R_1; therefore, it is known that the critical paths are $I \to S_2 \to M_2 \to D_2 \to R_1 \to E$ and $I \to S_2 \to M_2 \to D_2 \to D_3 \to R_1 \to E$ in this supply-chain network.

The available-to-promise (ATP) can be computed when the requirement due-date (RDD) is given by the customer. Given the RDD of the customer, the ATP of the supply-chain system can be identified and computed in accordance with equation (19). Suppose that the values of RDD are 13,15,18,20 and 25. If $\widetilde{R}$=(13,13,13) and $\widetilde{T}_{end}$=(13,18,25), then $\widetilde{R}\Theta\widetilde{T}_{end} = (-12,-5,0)$. The ATP of the supply-chain system can be computed as

$$ATP = \frac{\delta_1}{\delta_1 + \delta_2} = \frac{\frac{12*1}{2} - \frac{12*1}{2}}{\frac{12*1}{2}} = 0$$

Under this condition, the order-fulfillment degree of the supply-chain system is zero. This implies that the supply chain system cannot deliver on time.

If $\widetilde{R}$ = (18,18,18) and $\widetilde{T}_{end}$=(13,18,25), then $\widetilde{R}\Theta\widetilde{T}_{end} = (-7,0,5)$. The ATP of the supply-chain system can be computed as

$$ATP = \frac{\delta_1}{\delta_1 + \delta_2} = \frac{\frac{5*1}{2}}{\frac{(7+5)*1}{2}} = 0.42$$

Under this condition, the order fulfillment degree of the supply-chain system is 42%.
According to the different RDD values, the ATP of the supply chain system can be computed as shown in Table 3. According to Table 3, one can observe that if $\widetilde{T}_{end}$ is fixed and RDD is smaller, then the ATP of the supply-chain system is lower (shown in Figure 9).
Sometimes customers find it is difficult to define a crisp due-date; thus, it is reasonable for customers to give a fuzzy due-date in this scenario. For example, if the expected due-date is t, then the upper and lower dates will not be greater or smaller than 20% of the expected due-date. Thus, the fuzzy due-date is a triangular fuzzy number that can be denoted by (0.8t, t, 1.2t). According to Table 3, the crisp RDD values can be extended to fuzzy numbers as shown in Table 4. When RDD are fuzzy numbers, the ATP can be computed respectively.
If $\widetilde{R}_1 = (10.4, 13, 15.6)$ and $\widetilde{T}_{end} = (13, 18, 25)$, then $\widetilde{R}\Theta\widetilde{T}_{end} = (-14.6, -5, 2.6)$. The ATP of the supply-chain system may be computed as

$$ATP = \frac{\delta_1}{\delta_1 + \delta_2} = \frac{\frac{2.6 * 0.34}{2}}{\frac{(2.6 + 14.6) * 1}{2}} = 0.05$$

Under this condition, the order-fulfillment degree of the supply-chain system is 5%.
If $\widetilde{R}_2 = (12, 15, 18)$ and $\widetilde{T}_{end} = (13, 18, 25)$, then $\widetilde{R}\Theta\widetilde{T}_{end} = (-13, -3, 5)$. The ATP of the supply-chain system can be computed as

$$ATP = \frac{\delta_1}{\delta_1 + \delta_2} = \frac{\frac{5 * 0.63}{2}}{\frac{(5 + 13) * 1}{2}} = 0.18$$

Under this condition, the order-fulfillment degree of the supply-chain system is 18%.
When $\widetilde{T}_{end} = (13, 18, 25)$ and RDD are fuzzy numbers, the ATP of the supply-chain system can be computed easily shown as Figure 10. If the completion time of the supply-chain system is sooner than the requirement due-date of the customer, the operation time of members on the critical path can be shortened to reduce the completion time and increase the ATP. In other words, the proposed method can highlight the critical members and critical path obviously.

6. Conclusions

Along with the growth of information technology, the competition between enterprises has transformed into a competition between supply-chains. Thus, a robust management and operation model of a supply-chain system will increase the competitiveness for the enterprise. In addition, the order-fulfillment ability of the supply chain is the key factor for competitive advantage.
In this chapter, triangular fuzzy numbers have been used to express the various uncertainties in operation times. Combining fuzzy set theory and PERT, a fuzzy PERT is proposed in this paper to compute the fuzzy earliest-start-time, fuzzy earliest-finish-time, fuzzy latest-start-time and fuzzy latest-finish-time of each activity (member) in a supply-

chain network. And then, a critical degree index based on the fuzzy float time is defined to calculate the critical degree of each activity and path of the supply-chain system easily. The fuzzy model has been proposed to analyze the order-fulfillment ability of a supply-chain system with uncertain operation time. According to the proposed model, the status of each critical member of the system can be immediately understood. If the completion time of the supply-chain system does not satisfy the requirement due-date of the customer, we may adjust the operation times of the critical members to increase the ATP value and customer satisfaction. The simulation results show that if an enterprise on the critical path can reduce his operation time effectively, the order-fulfillment ability of the supply-chain network system may be increased.

In the future, additional uncertain factors such as crash time and crash cost will be considered for developing a fuzzy model to analyze the order-fulfillment degree of the supply-chain system.

7. Acknowledgements

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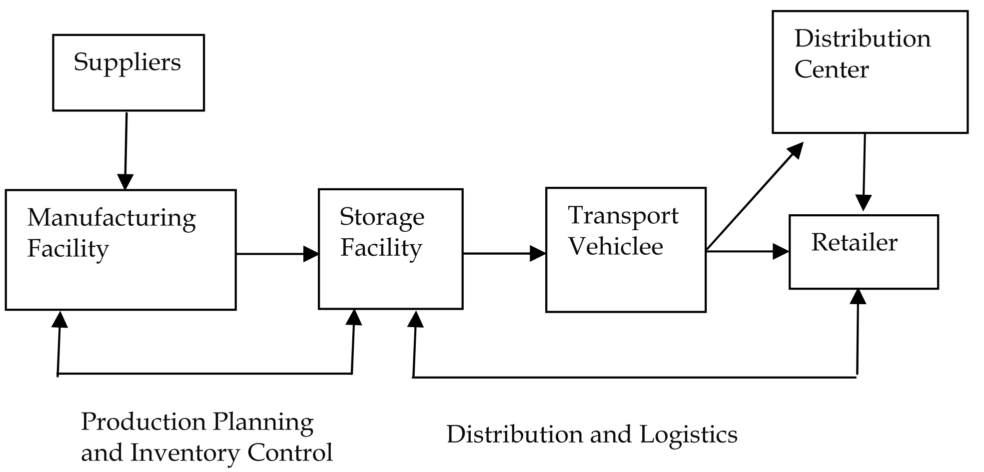

Figure 1. Supply-chain process [Beamon, 1998]

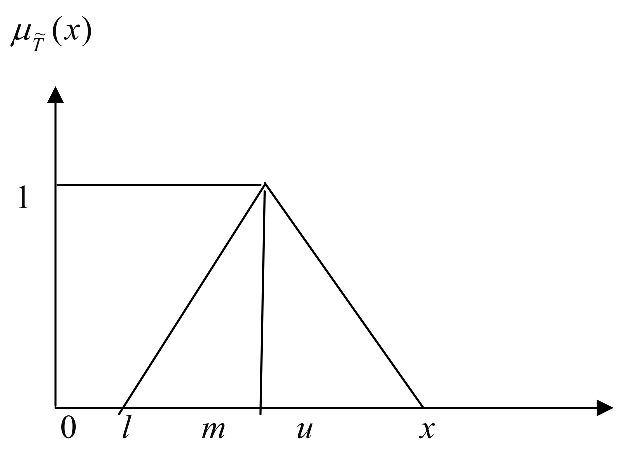

Figure 2. Positive triangular fuzzy number $\widetilde{T}$.

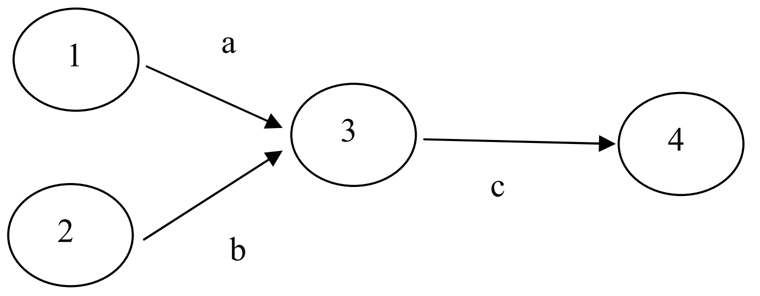

Figure 3. The graph of activity-on-arc (AOA).

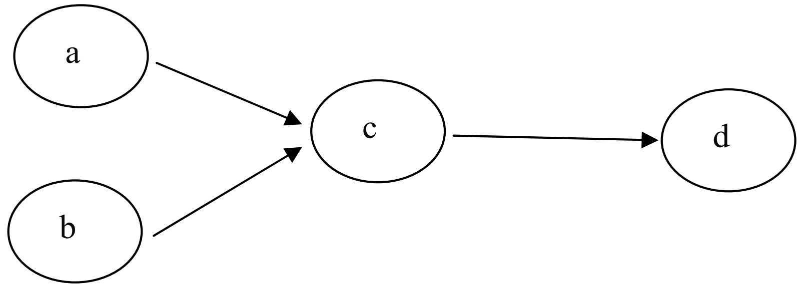

Figure 4. The graph of activity-on-node (AON).

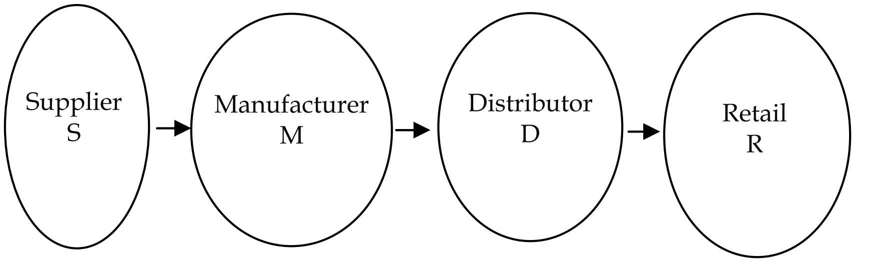

Figure 5. First type of supply chain.

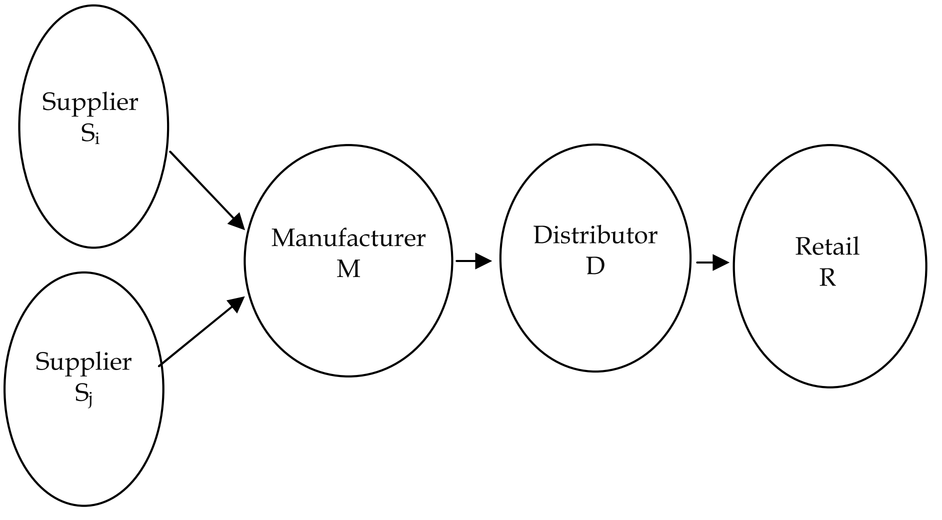

Figure 6. Second type of supply chain.

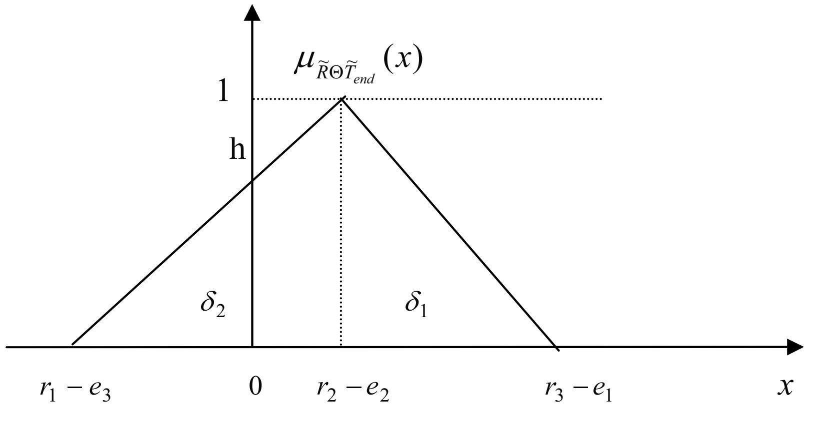

Figure 7. Membership function of fuzzy number $\widetilde{R}\Theta\widetilde{T}_{end}$.

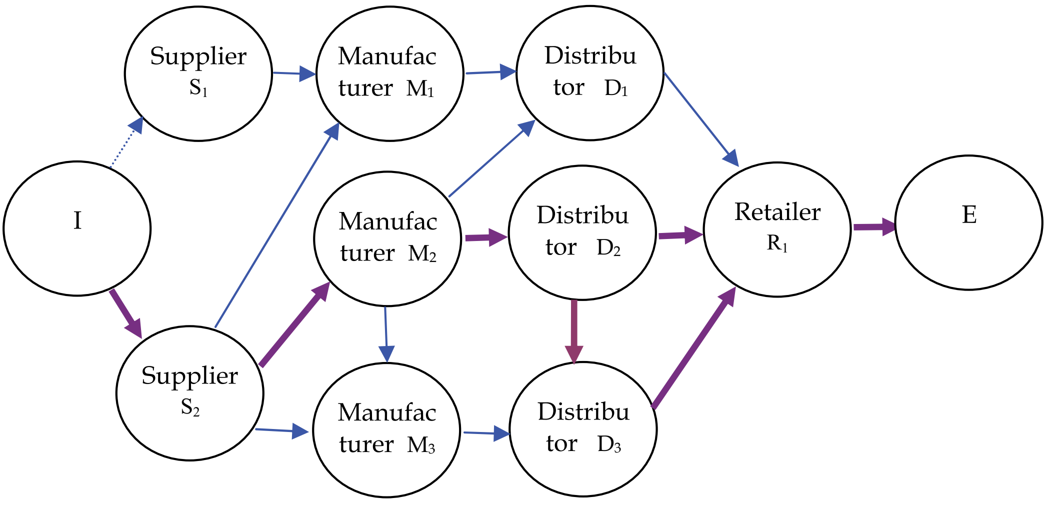

Figure 8. Graph of supply-chain network.

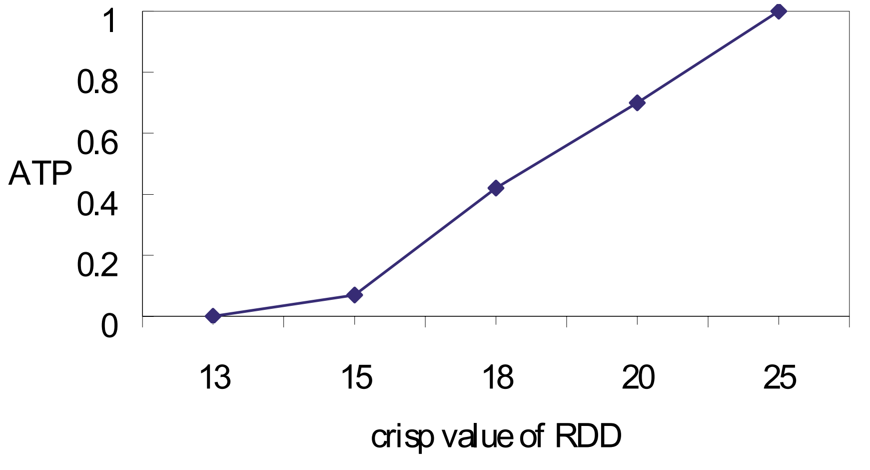

Figure 9. Crisp-value requirement due-date.

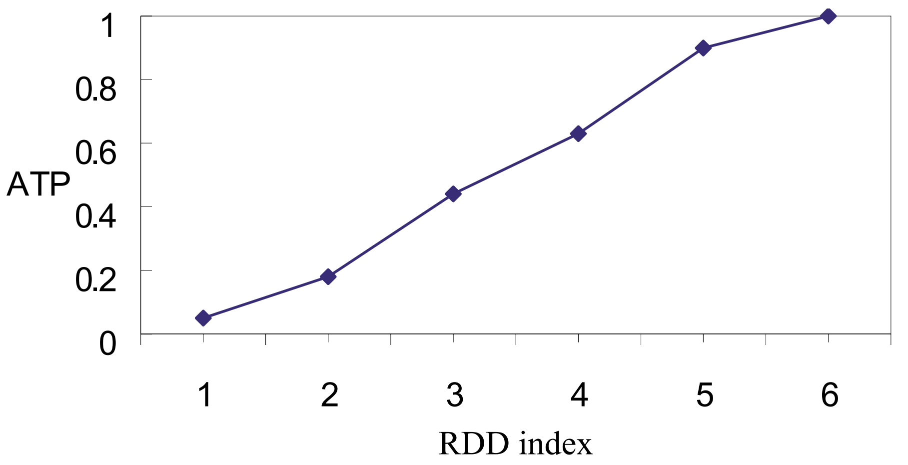

Figure 10. Fuzzy-number requirement due-date.

Node	Operation time	Earliest start time (ES)	Earliest final time (EF)	Latest start time (LS)	Latest final time (LF)	Float time ($\widetilde{m}$)	Critical degree
S_1	(1,3,4)	(0,0,0)	(1,3,4)	(-5,7,19)	(-1,10,20)	(-5,7,19)	0.42
S_2	(2,4,5)	(0,0,0)	(2,4,5)	(-12,0,12)	(-7,4,14)	(-12,0,12)	1
M_1	(2,3,6)	(2,4,5)	(4,7,11)	(-1,10,20)	(5,13,22)	(-3,6,15)	0.33
M_2	(3,4,7)	(2,4,5)	(5,8,12)	(-7,4,14)	(0,8,17)	(-9,0,9)	1
M_3	(2,3,4)	(5,8,12)	(7,11,16)	(1,9,18)	(5,12,20)	(-4,1,6)	0.8
D_1	(2,3,4)	(5,8,12)	(7,11,16)	(5,13,22)	(9,16,24)	(0,5,10)	0
D_2	(3,4,5)	(5,8,12)	(8,12,17)	(0,8,17)	(5,12,20)	(-5,0,5)	1
D_3	(4,4,4)	(8,12,17)	(12,16,21)	(5,12,20)	(9,16,24)	(-3,0,3)	1
R_1	(1,2,4)	(12,16,21)	(13,18,25)	(9,16,24)	(13,18,25)	(-3,0,3)	1

Table 1. Operation times for each member of supply-chain system.

No.	Path	$\pi(P_k)$
1	$I \to S_1 \to M_1 \to D_1 \to R_1 \to E$	0
2	$I \to S_2 \to M_1 \to D_1 \to R_1 \to E$	0
3	$I \to S_2 \to M_2 \to D_1 \to R_1 \to E$	0
4	$I \to S_2 \to M_2 \to D_2 \to R_1 \to E$	1
5	$I \to S_2 \to M_2 \to D_2 \to D_3 \to R_1 \to E$	1
6	$I \to S_2 \to M_2 \to M_3 \to D_3 \to R_1 \to E$	0.8
7	$I \to S_2 \to M_3 \to D_3 \to R_1 \to E$	0.8

Table 2. Critical degree of each path.

$\widetilde{R}$	$\widetilde{T}_{end}$	$\widetilde{R}\Theta\widetilde{T}_{end}$	ATP
(13,13,13)	(13,18,25)	(-12,- 5,0)	0
(15,15,15)	(13,18,25)	(-10,-3,2)	0.07
(18,18,18)	(13,18,25)	(-7,0,5)	0.42
(20,20,20)	(13,18,25)	(-5,2,7)	0.7
(25,25,25)	(13,18,25)	(0,7,12)	1

Table 3. ATP values when RDD are crisp values.

$\widetilde{R}$	$\widetilde{T}_{end}$	$\widetilde{R}\Theta\widetilde{T}_{end}$	ATP
$\widetilde{R}_1 = (10.4,13,15.6)$	(13,18,25)	(-14.6,- 5,2.6)	0.05
$\widetilde{R}_2 = (12,15,18)$	(13,18,25)	(-13,-3,5)	0.18
$\widetilde{R}_3 = (14.4,18,21.6)$	(13,18,25)	(-10.6,0,8.42)	0.44
$\widetilde{R}_4 = (16,20,24)$	(13,18,25)	(-9,2,11)	0.63
$\widetilde{R}_5 = (20,25,30)$	(13,18,25)	(-5,7,17)	0.90
$\widetilde{R}_6 = (25.8,32,38.4)$	(13,18,25)	(0.8,14,25.4)	1

Table 4. ATP values when RDD are fuzzy numbers.

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Assessing Improvement Opportunities and Risks of Supply Chain Transformation Projects

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1. Introduction

Planning and control systems have deeply evolved in recent years in order to cope with the needs of manufacturing firms. It is possible to identify a route of evolution that begins with the introduction of MRP systems (Orlicky, 1975) and, passing through the management of capacity and materials constraints, moves towards contemporary APS (Advanced Planning & Scheduling) and SCM (Supply Chain Management) solutions.
New functions, such as ATP (Available to Promise) or CTP (Capable to Promise), are nowadays considered necessary conditions for order planning and quoting. On the other hand, the offer of planning systems has reached a high level of performance with APS, where huge sets of objectives and constraints are standardised in libraries so that manufacturing systems can be modelled in detail.
APS/SCM systems represent the most relevant innovation in the world of manufacturing since the introduction of MRP systems in the Seventies (Turbide, 1998). In fact they marry the potentialities of modern processing systems with the most sophisticated heuristic / optimising / AI-based techniques developed by operations research.
Although most of the benefits provided by APS/SCM systems are generally quite apparent to operations managers which have to manage complex logistics system, a fair evaluation of these benefits should be provided by APS/SCM Vendors in order to prove that the huge amount of investment connected to the acquisition, implementation and maintenance of APS/SCM is paid back. In particular, the evaluation process could be divided into two different phases: the first one concerns the quantification of the expected improvement, while the latter focuses on the risks which could turn out in lower-than-expected returns. It is worth here specifying that the term “risk” could be intended not only to address negative cases (actual benefits lower than expected) but even positive cases (actual benefits higher than expected); moreover, when evaluating the project risk, intangible benefits (and drawbacks), such as the organisational impact of the IT project, should be considered.
This work describes the achievements of a research project, carried out at Politecnico di Milano, whose objective is to develop a new methodology, SNOpAck (Supply Network

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Opportunity Assessment Package), for the value assessment of APS/SCM system application in a supply chain.

The chapter is arranged as follows. Section 2 presents a brief literature review of value assessment approaches. Section 3 introduces a new methodology, which focuses on the value assessment of APS/SCM information systems. Section 4 presents a case study focused on the first 3 steps of the methodology (namely, 1. Preliminary analysis, 2. Analysis of operations and business processes and of Key Performance Indicators and 3. Evaluation of the APS/SCM solution). Section 5 reports some concluding remarks and suggests future research paths.

2. Theoretical framework

In recent years many studies have been focused on the evaluation of the possible benefits and costs related to the implementation of an information system into a company. Section 2.1 presents a survey of the most interesting contributions dealing with the value assessment of information system (IS) projects, whereas section 2.2 focuses on the project carried out at Politecnico di Milano, by highlighting its main features and goals.

2.1 Methodologies for the value assessment of IS projects

In the last three decades IS implementation has been one of the most important issues for the management of almost all kinds of companies. Several empirical studies have shown that organisations are not at all comfortable in the evaluation of IS investments (Willcocks & Lester, 1993). A large number of methodologies and techniques has been therefore proposed to help in the evaluation of IS investments. Different researchers could identify (Renkema & Berghout, 1997) over 65 methods supporting the evaluation of IS investments. Actually too many methods exist, "roughly one per consultant" (Farbey & Finkelstein, 2000), but most of them are not published from consultancy firms because of the possible loss of competitive advantage.

Several survey papers have shown that most methods of information system evaluation used in the practice, both ex-ante and ex-post, are variants of consolidated techniques and ways of thinking, which can be traced back to the following classification proposed by the works of Farbey *et al.* (1993) and Farbey & Finkelstein (2000): *i.* quantitative and comparative methods (or "objective" methods), provide a quantification of costs and benefits in economic terms, so allowing to compare the costs and benefits of different information systems; such methods usually rely on conventional accounting methods; *ii.* qualitative and exploratory methods (or "subjective" methods) emphasise the importance of understanding the opportunities as well as the threats which the change may bring to some stakeholders, with the aim of obtaining an agreement on the objectives through a process of exploration and mutual learning.

The classification framework proposed by Farbey *et al.* (1993) and Farbey & Finkelstein (2000) is reported in Tables 1 and 2.

Notice that, in spite of the wide availability of value assessment approaches, most companies apply simple accounting techniques, belonging to the cluster of quantitative and comparative methods: Ballantine & Stray (1999) carried out a survey showing that the most

used methods for the evaluation of IS projects in companies are still ROI and Cost-Benefit Analysis methods.
Finally, it is worth highlighting that researches validating evaluation methods are hardly available and that general prescriptions about the use of which method in which circumstances can not be given (Renkema & Berghout, 1997).

2.2 Value assessment of APS / SCM projects

When dealing with the introduction of information systems for Supply Chain Management in a company, the topic of identifying and analysing the extent of change and of the expected benefits (value assessment) is a key issue and no universally accepted methodology can be found in literature, although the task of evaluating the benefits appear simpler in this case, since the benefits are restricted to Operations.
The proposed methodology supports both industrial users during the process of "ex-ante" evaluation of the opportunity to implement an APS/SCM solution and consulting firms during the process of definition of the features to which address a possible choice of a specific information system solution. The main goals driving its development are completeness, objectiveness and possibility of a partial automation. It has resulted an analytical methodology that, recalling the classification by Farbey *et al.* (1993) and Farbey & Finkelstein (2000) (see Table 1), can be classified in the group of "cost-benefit analysis" methodologies although it has some distinguishing features that will be deeply presented in the following section.

3. THE SNOpAck methodology

At Politecnico di Milano a research project was carried out with the aim of developing an original value and risk assessment methodology, called SNOpAck (Supply Network Opportunity Assessment Package), for evaluating APS/SCM implementation projects. When dealing with an implementation project in a specific company, the methodology aims at answering to the following three main questions:

i. which information requirements should be addressed in order to improve company's operations?
ii. which benefits would arise by fairly covering such requirements?
iii. which is the **Value** (in terms of quantifiable benefits and costs) related to a specific APS/SCM solution?

An overview of the steps of the SNOpAck methodology is presented in Figure 1; each step will be described in the following sections; further details are reported in Fahmy Salama (2002).

Method	Detail	Process management	Data	Features
Cost/ revenue analysis	Very high	Accounting and costing staff	Cost accounting and work-study method	Focus on cost savings and cost displacement
Return on investment (ROI)	High	Calculation by professionals; tangible costs and benefits aggregated as cash flows	Tangible; direct; objective	Ex ante and ex post ; future uncertainty is considered; middle to high cost
Cost-benefit analysis	High	Bottom up; carried out by experts; money values for decision makers by incorporating surrogate measures	Cost and benefit elements expressed in a standard money value form; pseudo-objective	Ex ante or ex post ; cost-effective solutions; "external" and "soft" costs and benefits; numbers more important than process; high cost
Return on management (ROM)	Low	Calculation by professionals; manipulates accounting figures to produce a residue – value added by management	Accounting totals (e.g. total revenue, total labour cost)	Ex post; no cause and effect relations can be postulated; utilisation of a formula; cheap
Boundary values and spending ratios	Low; aggregate	Top-down; senior stakeholders involved; calculation by professionals	Ratios of aggregated numbers (e.g. IT expense per employee)	Ex ante or ex post ; supporting benchmarking analysis; cheap
IE, information economics	Usually very high	Many stakeholders involved; detailed analysis required	Ranking and rating of objectives, both tangible and intangible	All options are comprehensively dealt with; rather complex

Table 1 – Quantitative and comparative methods (Source: adapted from Farbey et al. (1993) and Farbey and Finkelstein (2000)

Method	Detail	Process management	Data	Features
MOMC, multi-objective, multi-criteria	Any level	Top-down; consensus seeking; all stakeholders involved; best choice is computed	Priorities are stated by stakeholders; subjective evaluations of intangibles	Ex ante; good for extracting software requirements; process is more important than numbers; selection of (a) preferred set of design goals, (b) best design alternative; high cost
Value analysis	Any level; generally detailed	Iterative; senior to middle management involved; variables identified by means of Delphi method	Indirect; subjective evaluations of intangibles; utility scores	Ex ante; iterative; incremental; focus on added value than on saved cost; process is more important than numbers; high cost
Critical success factors	Short list of factors	Senior management define CSFs	Interview or self-expression; Quick but consuming senior management time	Ex ante; highly selective
Experimental methods	From detailed to abstract	Management scientists working with stakeholders	Exploratory; uncertainty reduction	Ex ante

Table 2 – Qualitative and exploratory methods (Source: adapted from Farbey et al. (1993) and Farbey and Finkelstein (2000).

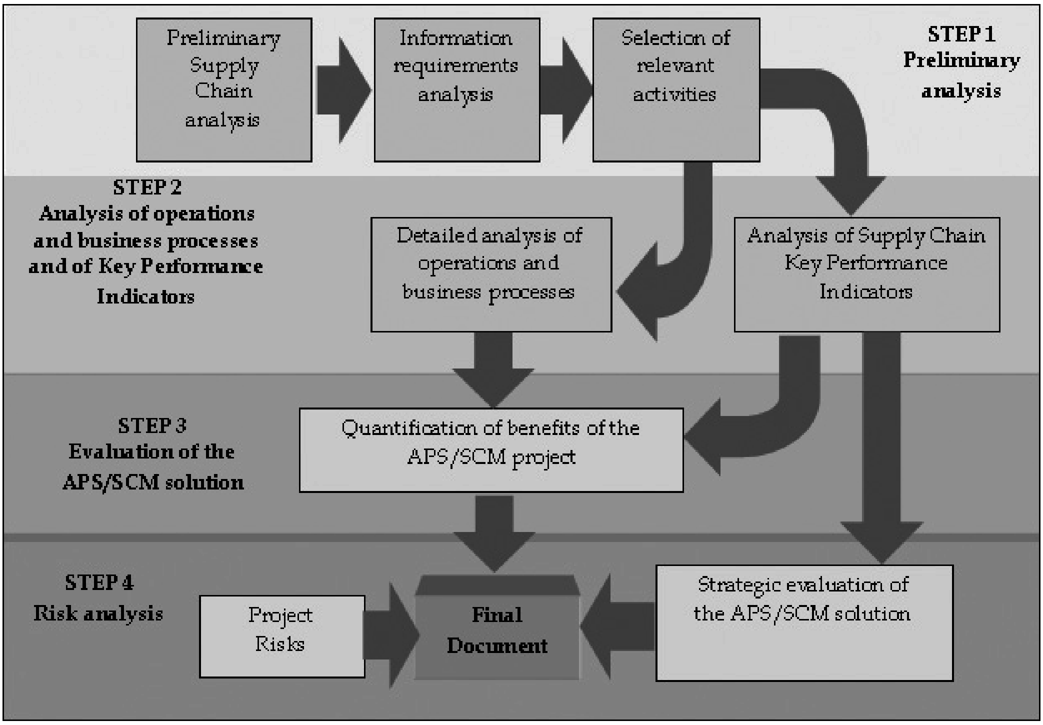

Figure 1. Structure of the SNOpAck methodology

3.1 Step 1: preliminary analysis

In the first phase, after a preliminary analysis of the organisation, an information requirements analysis is carried out. Through a structured questionnaire, a weight is associated to each information requirement, so to classify each of them in a range from "irrelevant" to "highly relevant". In order to counterbalance the subjectivity of the company's interviewee, the weights are corrected by identifying the supply chain typology that best suits the observed company. In particular, adapting the work of Fisher (1997), three main typologies have been identified, as depicted in Table 3: "efficient" supply chains for "functional" products, "quick" (or agile) supply chains for "innovative" products and "flexible" supply chains for "complex" products. The observed company can present a mixture of the above stated typologies; once the specific supply chain typology is identified, the weights are corrected by taking into account the typical pattern of information requirements which characterise that supply chain typology.

Once the information requirements analysis has been carried out, the most relevant requirements are selected by referring to a threshold value of the weights. For each of them, a set of activities supported by APS/SCM systems and fulfilling the information requirements are defined: these activities are "relevant", in that their execution has a considerable impact on supply chain performance.

3.2 Step 2: Analysis of operations, business processes and Key Performance Indicators

The aim of this phase is the identification of company's performances improvement due to the implementation of the APS/SCM system. In order to carry out this step, a set of Key Performance Indicators (KPIs) has been identified and, later on, an "activities-performances relationships matrix" and a structured approach for KPI improvement evaluation have been developed.

As far as the KPIs are concerned, the performances considered in this methodology to evaluate the impact of APS/SCM solutions on organisations are based on a survey of the dashboards employed to measure the effectiveness and efficiency of logistic-production systems found out in literature, e.g. the metrics proposed by Bowersox & Closs (1996), Stadtler & Kilger (2000) and in the SCOR model (Supply Chain Council, 2003). The resulting KPIs can be classified in three main groups:

i. effectiveness performances, which address performances actually perceived by customers (e.g. on-time deliveries, delivery lead time);
ii. efficiency performances, which address performances not directly perceived by the customers (e.g. stock levels, work in process, resources saturation);
iii. automation performances, which address the improvement in efficiency due to the automatic execution of formerly manual activities (e.g. order entry, order release).

Moreover, by observing that in many cases a performance improvement leads to an indirect improvement of other performances, a cause-effect relationships network linking the KPIs has been developed. An example of relationships network is provided in Figure 2.

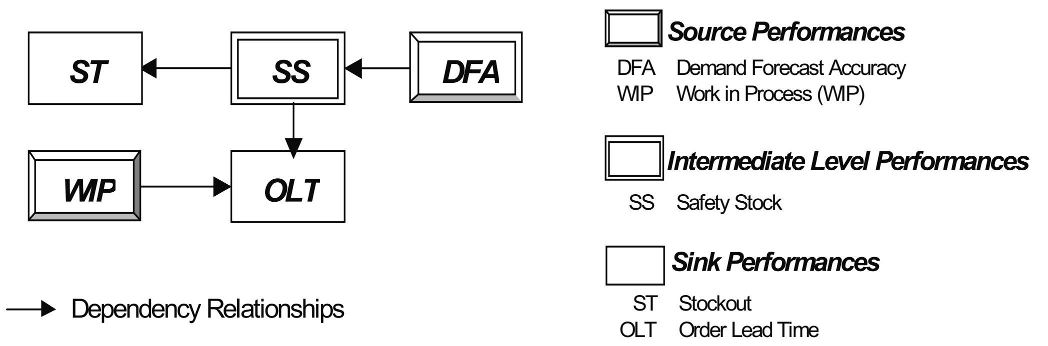

Figure 2. Example of relationships network.

For any of the activities identified in the previous step, the "activities-performances relationships matrix" supports the identification of KPIs affected by a streamlining of the activity itself, thus allowing a rapid definition of the "relevant" KPIs for the analysis and assessment of benefits. Figure 3 depicts the process of identifying the critical KPIs starting from the weighted information requirements.

	SC typology		
	Efficient	Quick	Flexible
	Products features		
BOM complexity	Low	Low	High
Lifecycle duration	> 2 years	3 months – 1 year	> 2 years
Contribution margin	1 % – 15 %	> 50 %	> 10 %
Product variety (variants per category)	Low (10-50)	High (>300)	High (>300)
Average forecasting accuracy (error)	<10 %	> 40 %	-
Average stock-out level	1 % - 3 %	> 10 %	-
Average discount at lifecycle end (as percentage of the price)	0 %	10 % - 30 %	-
	SC features		
Main goal	Cost efficiency	Demand is satisfied efficiently, by minimising stock-out, discounted selling and stock obsolescence	Timeliness in demand fulfilment
Manufacturing focus	Keeping high the manufacturing equipment utilisation rate	Keeping some excess of manufacturing capacity	Maximising operative flexibility
Lead-time focus	Light reduction strategy	Aggressive reduction strategy with big investments	Aggressive reduction strategy by means of big investments
Integration level	High both with upstream and downstream partners	High both with upstream and downstream partners	High with upstream partners
Vendor selection approach	Selected by cost and quality	Selected by speed, flexibility, quality	Selected by speed, flexibility, quality
Inventory strategy	Keeping a high rotation rate and minimising inventory along the SC	Minimising inventory though avoiding stock-out in new products launch phase	-

Table 3 –Supply Chains typologies (Source: adapted from Fisher (1997)).

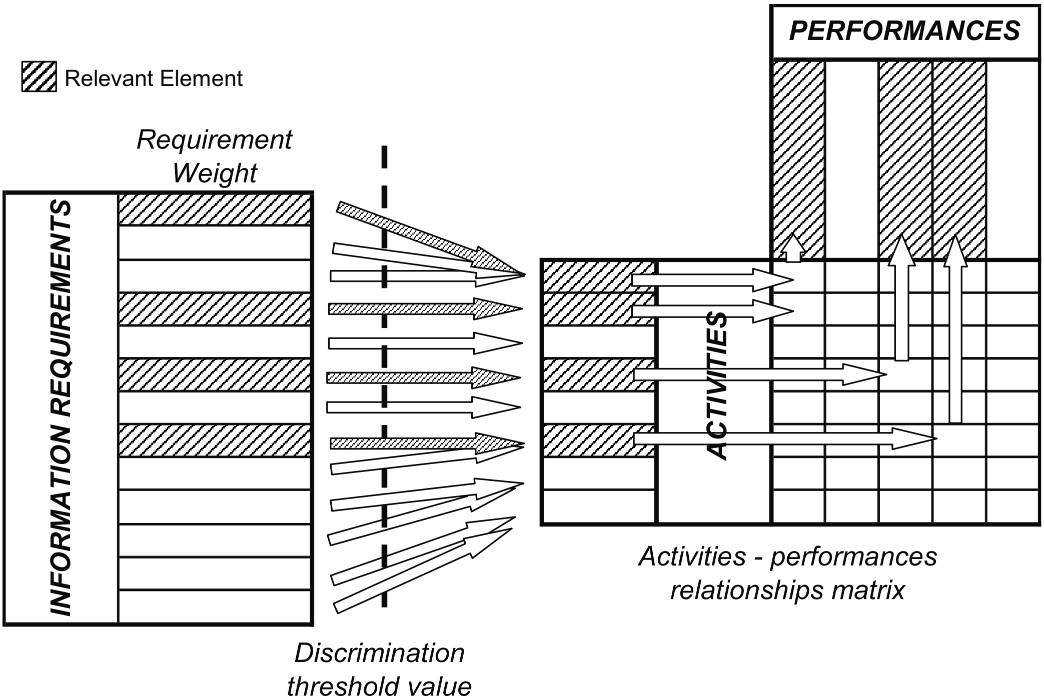

Figure 3. Tool for rapid selection of relevant activities and performances.

Finally, the structured approach for KPI improvement evaluation supports the assessment of KPIs improvement by considering the following elements:

i. the actual widening of KPI value improvement ("performance gap");
ii. which factors determine the performance gap ("cause factors", e.g. supplier delays, unreliable production plan), if the gap exists.

When applying the structured approach, a company's manager is to support the identification of the previous elements. Then, for each KPI, an analysis is carried out (jointly with the company's manager) with a twofold aim:

i. a weight of influence on the performance gap is assessed for each cause factor and for each influencing performance (recall Figure 2); the weights sum is 100%;
ii. the percentage reduction of each cause factor due to the adequate support of the "relevant" activities is esteemed

The overall percentage reduction of the performance gap is then calculated as a composition of the cause factor reductions and of the cause performance improvements (cause performance improvements have been previously calculated by means of the same structured approach). Figure 4 depicts the structured approach as a whole.

When it is possible, besides the performance gap analysis, quantitative analysis methods can be applied to determine the performance improvement (e.g. resource saturation).

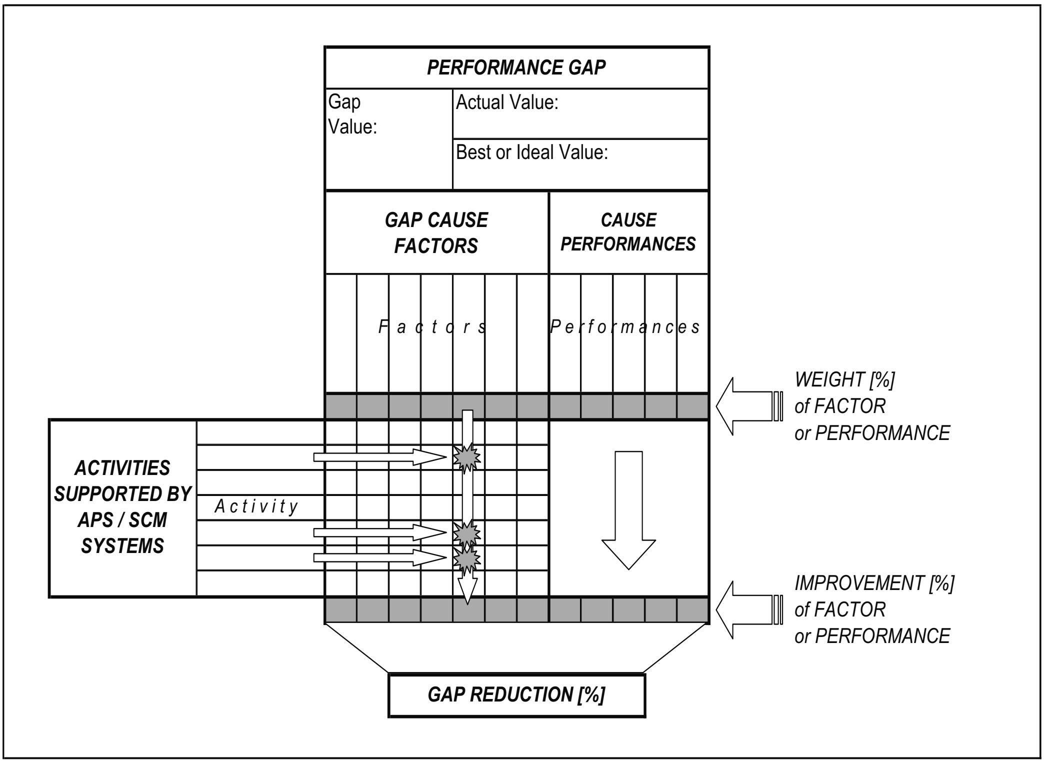

Figure 4. Performance gap analysis.

3.3 Step 3: Evaluation of the APS/SCM solution

In the third step, the final assessment of the introduction of an APS/SCM solution is carried out, by quantifying the APS/SCM benefits (Figure 5). A performance improvement usually implies a measurable economic gain in the short term, due to an improvement of supply chain efficiency or effectiveness or to a cost reduction for the automatic execution of former manual activities.

Besides the short-term quantitative benefits, possible intangible benefits may arise from the implementation of an APS/SCM system. For instance, these benefits may be related to an improvement of the competitive advantage (e.g. an improvement in customer order timeliness has an impact on customer service level), or to the organisational impact of the system (e.g. an APS/SCM project usually implies a redesign of tasks and roles or even a change management). Although it is hard to define the economic gain for the improvement of intangible performances, it is important to check their improvement with the overall business strategy for the supply chain management, when considering the opportunity of implementing an APS/SCM information system solution. This topic is the object of the following section.

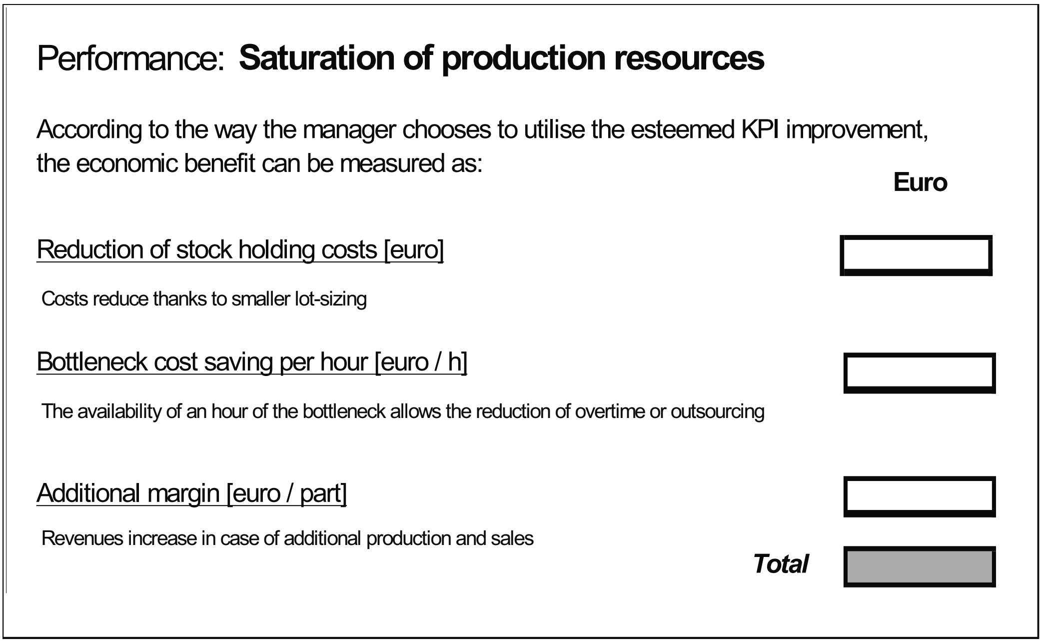

Figure 5. Benefits evaluation.

3.4 Step 4: Risk analysis

Once the expected tangible benefits related to the implementation of an APS/SCM solution have been evaluated, a further analysis is carried out, taking into consideration risk and intangible aspects; the analysis methodology has been developed on the basis of cognitive psychology (Kahnemann *et al.*, 1982). In particular, the aim of the analysis is threefold:

i. to determine the probability associated to each possible project outcome;
ii. to estimate the transient duration before the benefits are gained;
iii. to complement the quantitative analysis with a comprehensive set of qualitative considerations (the so called *strategic issues*).

An interesting side result of the proposed risk analysis is the evaluation of manager's own risk attitude, which helps in comparing different APS/SCM projects whose outcomes present different discrete distributions. Moreover, the risk analysis determines a ranking of the project risks, according to their impact on project results; this information is extremely important since it supports a focused monitoring of the risk factors which may threaten the project's success.

A case study presenting in detail the functioning of the Risk analysis is presented in Brun *et al*. (2006).

4. Rigamari case study

This section presents an in-depth case study of application of the SNOpAck methodology to a mechanical company, Rigamari (albeit being a real company, the company name has been disguised). Once analysed the defects (in terms both of inefficiencies and ineffectiveness) of

Rigamari supply chain planning process, SNOpAck methodology allowed to assess the value of the implementation of a APS system for supporting gas turbine production. After a detailed description of the company and, mainly, of the difficulties its supply chain suffered, this section reports the application of SNOpAck methodology.

4.1 Company presentation

When it was established, in 1842, Rigamari was a small Italian entrepreneurial metal alloy foundry, which entered in the mechanical production in the first few years of 20th century. In 1994 the company was acquired by an US-based multinational company. The core business of the company concerns the production of compressors, gas and steam turbines for oil and chemical plants, pumps and compression facilities, gas valves and gauges, petrol pumps, control systems for looms. Production activities take place in one of the 7 Italian plants of Rigamari among which, the most prominent are those based in Florence and in Borgo Ricco.

Borgo Ricco plant encompasses overall 80,000 square meters: 65,000 m^2 dedicated to machine and assembly operations of 3 different product lines: blades for steam and gas turbines, gas gauges and fuel pumps. Overall, 130 workers are employed in the production of blades for gas and steam turbines: in the last 2 years turnover for this product line has more than doubled, reaching 56 Million Euro. Once completed, blades are sent to the main Florence plant, where they are then assembled, in order to build the final machine. Besides, within the Florence plant are located the company offices (sales, R&D, etc.). Within Borgo Ricco plant, *gas turbines* accounts for the 80% of blades production, while *steam turbines* production (and, on turn, production of blades for steam turbines) accounts for the remaining 20% of orders. The case study will focus on *gas turbine* production.

A *gas turbine* employs two different kinds of blades: one for the compression stage and another for the turbine stage – in the latter stage, blades are hit by exhaust gas with an extremely high energy content. Both blades for the compression stage and the turbine stage are standardized, then different turbines normally adopts blades with the same characteristics.

Blades for gas turbines are obtained by machining operations on a die-cast piece produced by an external supplier. Work-cycle encompasses rectification, thermal treatments (realized by sub-suppliers) and a plethora of severe quality controls and checks (both during or after operations).

Components of a gas turbines are divided into two groups: *i*. "critical" components, having a long production (or supply) lead time, are manufactured (or supplied) on the basis of forecasts; *ii.* "non-critical" components are made to order. About the 100% of components realized within the Borgo Ricco plant are classified as critical.

The short term planning of blades production activities are derived from the mid-term planning of gas turbines, directly managed by Florence headquarter. The chief commercial manager is in charge of deploying a sales budget, based on historical data and forecasts. The Master Production Schedule is based on the sales budget and spans over a 12-month period.

Once the MPS has been determined at Florence, the headquarter communicates to Borgo Ricco components requirements according to MPS and an additional set of forecasts spanning over the time period not covered by the MPS.

Technically, the workload at Borgo Ricco is managed according to *advanced order* logic: that is, components are manufactured before the actual purchase order is issued by a customer.
Theoretically speaking, the period covered by the MPS would be long enough to cover the information requirements at Borgo Ricco, since the overall lead time at Borgo Ricco is 10 months, on average. Nonetheless, requirements issued by Florence plant are not definitive: Commercial Officers in Florence revise sales budget every month (and components delivery dates are changed accordingly). As it could easily be guessed, this is a bit of a problem for Borgo Ricco planners, especially when delivery dates are anticipated. In such situations, production activities are rescheduled manually, since planners do not have any information tool supporting urgent order scheduling (such as a "capable-to-promise" tool).
The die-cast for the turbine section blades are ordered by Florence; as a consequence, after receiving the requirement for a set of blades, Borgo Ricco plant should also receive the die-casts.
As for the compression section, raw materials are ordered by Borgo Ricco: the production manager checks the availability of raw materials, and then communicates the net requirements to the purchasing department. Raw materials suppliers are divided in two groups according to the kind of supply relationship with Rigamari: *i. transactional relationship*, that is an arm's length relationship wherein each purchase is considered as one of a series of independent deals, and delivery conditions and purchase price are re-negotiated at every single deal; *ii. long-term agreements*, in this case an agreement is signed up between the two parts, so that on the one hand Rigamari undertakes to purchase a certain volume for the next 12 months, on the other hand the supplier undertakes to deliver goods within reduced supply lead times.
Borgo Ricco plant operates with "zero inventory": machining operations can start only after the arrival of raw materials for gas turbines blades. Unfortunately, delivery timeliness is by far smaller than 100%. Nevertheless, due to the "zero inventory" objective, the make-to-order logic theoretically eliminates obsolete stock; moreover the inventory levels of consumables and spare parts is not relevant.
Each production line is basically dedicated to the production of a specific kind of blade. Production planning and control is carried out by the planning office, encompassing 6 workers, along with the shop-floor responsible. In particular, the shop-floor manager is in charge of short term production scheduling, taking a series of decisions based on past experience, aimed at maximizing resource utilization (mainly by minimizing set-up times; in fact the direct variable cost of scheduled resources has a small impact upon overall variable cost of the end product). Such scheduling activities are supported by a spreadsheet with manual data-entry.
Urgent orders, mainly due to last-minute modification in product's technical specifications decided in Florence, account for a 60% of total orders and invalidate schedule effectiveness.
The issuing of warning signals (such as in the case of the break-down of machines, urgent orders, etc.) is carried out in an informal way and it is not automated, since the shop floor and planning office are close to one another. When interviewed, planners stressed the lack of a more 'active' management of such exception signals: they would welcome, for instance, the possibility to simulate alternative scenarios in order to briskly identify the best possible course of action.

On average, overtime accounts for one hour per day per worker on the shop floor; this is anyway not enough, and Borgo Ricco must often rely on production capacity of sub-suppliers (even though the Borgo Ricco plant has the technological capability to carry out the work) to carry out the required workload. As stated by the planning department manager "I'd rather hire another 20 guys; still, without those folks, there is yet another way to meet Florence requirements: to set-up an adequate information system". Both the amount of investments and hired personnel at Rigamari must abide the strict regulations determined by the holding company board.

Quality control activities are also manually planned and predictive maintenance is not considered relevant. Quality control stations are considered as a part of the production system and do not have particular planning criticality. Product quality is regarded as a Critical Success Factor at Rigamari. That's the reason why new products are always 100% tested, while sampling acceptation is only carried out in case of products with a significant reliability history. Such an effort in terms of quality control is necessary, due to the high costs of external failures (a broken blade would mean stopping the turbine and, in turn, a very high hourly loss for Rigamari customer). In the last few years, quality levels (mainly measured by the level of external failures quality costs) reached by Borgo Ricco have steadily been more than satisfactory and there is no intention to spend any additional effort to improve the planning of quality control activities.

Some of the phases of the blades production cycle (as, for instance, thermal treatments) are executed by sub-suppliers. The information exchange between Rigamari and sub-suppliers (in particular in terms of visibility on production advancement at the sub-suppliers premises) takes place on a completely informal base. The same holds true for the suppliers: visibility on supplier processes is particularly limited when the purchase order for rough pieces is issued by Florence.

Suppliers and sub-suppliers expediting and production advancement control are carried out by 4 employees at the Borgo Ricco plant plus an additional (external) person, by means of telephone or fax reminders. An increased visibility over external production would therefore be very welcome.

Once production is terminated, finished blades are immediately sent to Florence plant. Basically, Rigamari outsources most of its transportation activities to third-party carriers. The portion of transports managed internally (i.e. with Rigamari's own fleet) is not critical at all, since there is only one single destination (from Borgo Ricco to Florence, and back) and departures are scheduled on a daily basis; besides, transportation costs are not so significant and truckloads are always 100% full.

Supply Chain performance is controlled directly by Florence officers; in particular, after the delivery of a machine to the end customer, several logistics KPIs are calculated on an *ex-post* basis.

4.2 An overview of Borgo Ricco plant problems

In the last 6 months, production levels have more than doubled (they have started working on a 24/7 basis - 3 daily shifts, 7 days per week) and sub-suppliers workload has increased accordingly, accounting for 50% of the overall production. In this situation, Borgo Ricco situation has become unbearable.

One of the major problems of Borgo Ricco production planning and control system is related to timeliness and punctuality of raw materials delivery for both turbine and compression sections. Raw materials suppliers are large steel manufacturers, having great negotiation strength; by basing their production on long production campaigns, they often change their supply lead times with very short notice (being such a small customer, Rigamari cannot argue about that).

Moreover, for compression section blades, there is also the need to closely control the external production capacity, with special regards to the first few production phases.

Performance of turbine section blades production is affected by the late delivery of rough pieces from Florence, often later than the planned completion date of finished blades. Another problem is low production capacity of suppliers in charge of executing either complex or highly specialized processes: planning such suppliers production on the basis of reliable forecasts would very important to Rigamari.

Production planning is also disturbed by frequent requests from Florence to accelerate deliveries. Such requests are driven by the quarterly financial goals declared to stakeholders: not to run the risk to under-perform, managers at Florence headquarter strive to anticipate end-of-quarter deliveries in order to remain on target.

Since there is no possibility to protect the production systems against exogenous variations and disturbance with safety stock (as stated before, the holding company requires to work with "zero inventory"), the only source of flexibility is sub-suppliers production capacity (which, as a matter of fact, is systematically used by Rigamari). In order to rely on such source of flexibility, Borgo Ricco has to take into account both sub-suppliers' lead times and production capacity constraints. Each month, Rigamari issues an order for generic production capacity (without specifying the exact use) – it is a sort of "advanced booking" of production capacity. In order to book the right amount of production capacity, at the right time, Rigamari has to forecast correctly production requirements (over a one-month time period) and at the same time to time-phase requirements and available capacity in order to utilize booked capacity in the best possible way (i.e. both in an efficient and effective way).

4. 3 SNOpAck methodology application

The preliminary analysis of the company was carried out by means of informal interview with plant manager and production manager, and was focused on the evaluation of an APS/SCM tool for improving Borgo Ricco performances in gas turbine production. The operations of Florence headquarters were considered as out of scope. The main output of the first step of the methodology was the list of relevant information requirements, which follows:

- **Simulation of production activities**: typical of highly flexible manufacturing systems; it allows to evaluate the impact of different schedules in term of machines workload and material availability;
- **Integration with suppliers:** in terms of both *visibility to suppliers* (it allows to suppliers all along the supply chain to align their planning processes to final customer demand and, in particular, to align capacity with demand as soon as demand changes show up, thus avoiding the typical delay and bullwhip effects) and v*isibility on suppliers* (it allows

to evaluate in advance the effects of several purchase alternatives and to communicate reliable delivery dates to the end customer)

- **Sub-suppliers planning and control**: typical of companies heavily relying on sub-suppliers, it gives visibility on third-party production activities (quality control, production advancement, etc.).
- **Alert management**: it allows to have real-time information on exceptions, bottlenecks, capacity constraints violation, thus allowing to promptly adjust plans accordingly.
- **Integration with customers**: mainly in terms of visibility to customers (Florence), allowing to increase service level offered to customers, in terms of reliable and frequently updated (if necessary) delivery dates, immediate order confirmations, possibility to make variations in the order conditions based on actual production advancement, etc.
- **Available to Promise/Capable to Promise (ATP/CTP)**: it allows to communicate to the customer reliable delivery dates based on available materials (raw materials and components, assemblies and sub-assemblies, finished products) and available production capacity. This requirement is most relevant in case of complex Bill of Materials, with many levels and long production cycles – especially with assembly operations requiring the co-ordination of several independent production flows.

On the basis of the list of information requirements, a set of relevant activities to be supported by APS/SCM was determined. They are: production programming, suppliers and sub-suppliers integration and planning, alert management, integration with customers and stock management, order promising (ATP/CTP).

Once the activities were determined, we moved on to step 2, with the aim of quantifying the improvement of KPIs due to APS/SCM implementation. This step was successfully carried out by referring to the activities/performances relationship matrix, which allowed to identify the set of relevant Borgo Ricco KPIs which can be improved thanks to the APS/SCM system, and by referring to the relationship network tool (see Figure 2) it was possible to determine the KPI which are expected to improve due to some improvement in upstream (first-tier) KPIs. The resulting relevant performances were: timeliness, on-time delivery, resources saturation, work in process (WIP). Once the relevant KPIs were identified, the improvement of each of them was quantified by means of structured approach for KPI improvement evaluation (see Figure 4) or analytically. Some examples are reported in the following.

Resource saturation reduction

7 rectification machines operating on 3 daily shifts for about 300 days per year:

- Total time = 50,400 hours/year
- Scraps = 330 hours/year
- Break-downs = 500 hours/year
- Problems due to Operators = 1,600 hours/year
- Set-ups = 7,500 hours/year

By simulating alternative schedules with lower overall set-up time due to better sequencing of similar jobs, it was possible to estimate that the improvement of planning activities could bring to a reduction of set-up times of about 30% → 2,250 hours per year (4.5% of total time).

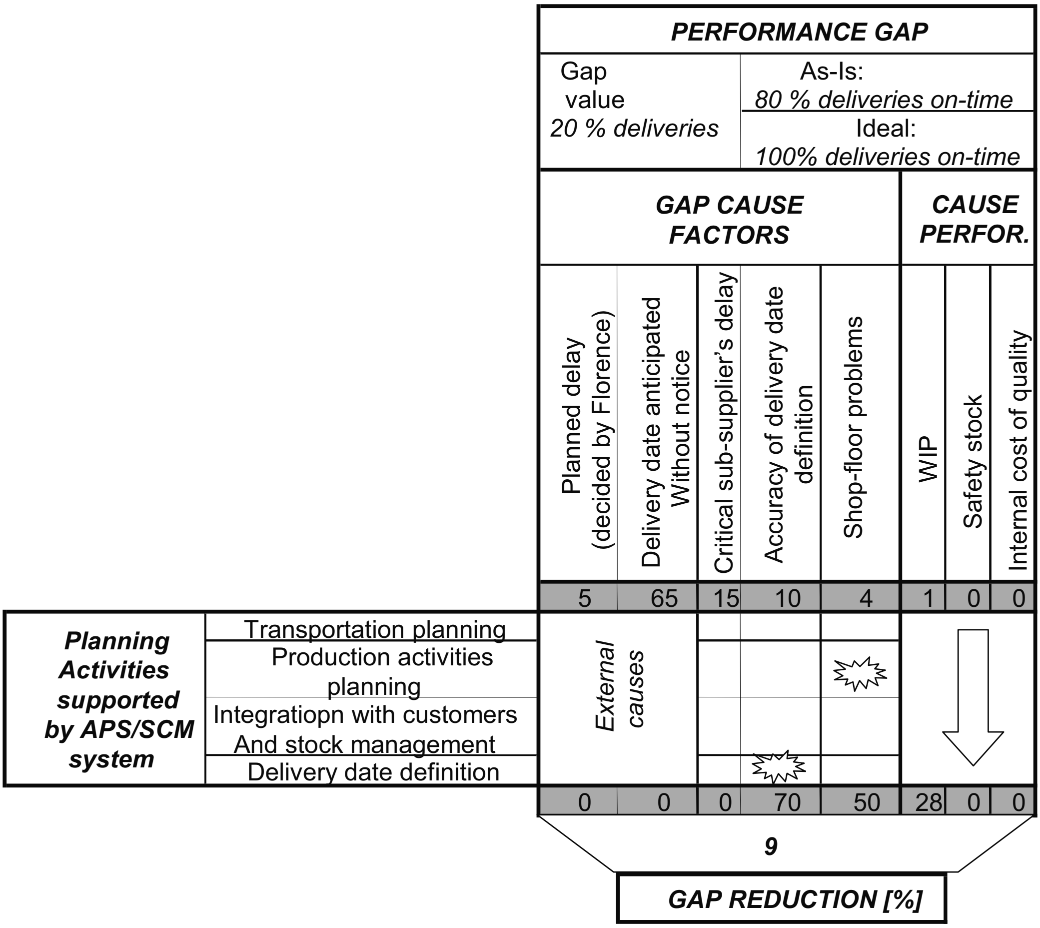

Figure 4.

The estimated improvement are here summarised:

- timeliness: from 8 month to 7.5 month;
- on-time delivery: from 80% on time delivery to 82% on-time delivery;
- resources saturation: 4.5% of total time freed up for further production activities;
- work in process (WIP): from 220 sets of blades sets to 205 sets of blades.

During step 3, the improvements of timeliness and on-time delivery have not been quantified: their improvement positively impact on the company image of fast and reliable deliveries. On the contrary, the improvements of resource saturation and WIP have been quantified as follows:

- Resource saturation:
  - o Set-up reduction would free up production capacity (2,250 hours/year)
  - o Average productivity of rectification machines: 10 pcs/hour
  - o Direct variable costs for rectification process: 1.40 €/piece

  - Sub-supplier cost: 10 €/piece
  - Annual savings: 193,500 €
- WIP:
  - WIP reduction: 14 sets of blades (1 set = about 80 blades)
  - Direct variable costs: 850 €/unit
  - Average completion degree: 50 %
  - Opportunity cost of capital: 10 % per year
  - Annual savings on inventory holding costs: 47,600 €

Then, after transient time, an overall annual saving of about 250,000 € is expected.

As for the costs of the APS/SCM system, they were provided by the IT vendor which had just finished to successfully implement its APS/SCM system in Florence plant. The APS/SCM system fully satisfied the information requirements identified for Borgo Ricco, then that vendor appeared a good candidate for APS/SCM implementation in Borgo Ricco.

According to the last step of SNOpAck methodology, the strategic evaluation of the APS/SCM solution was carried out. The main elements of the analysis are reported in the following:

- the improvement of on-time delivery and of timeliness strongly contribute to the improvement of the image of Borgo Ricco and of the company as a whole;
- the APS/SCM system frees up time of planner employees which can be diverted into improving planning decisions (being more efficient allows to be more effective);
- project risks have been determined (data availability and correctness (g.i.g.o. rule); top management commitment; employees training) and strong attention should be devoted to them throughout the project otherwise they could undermine APS/SCM implementation success;
- the transient time to have the new APS solution up and running was estimated to last about one year; moreover, given the variability associated with some of the figures included in the saving estimation, benefits in the following years were protectively set to just 80% of the expected 250,000 €/year foretold by the procedure in Step 3.

The cash flows have then been recalculated considering the outcome of the risk analysis, and considering an overly cautious discount rate of 20%/year (worst case). As a result, the pay-back time for the implementation of the new APS/SCM system is estimated to be as short as 10 months.

5. Conclusions and future developments

Over the last 5 years, the model has been applied to more than a dozen manufacturing and service organizations belonging to different sectors. The cases were useful to identify strengths and weaknesses of the methodology. The objectives of completeness and objectivity are reached and many of the hypotheses of relations between management activities and KPIs were confirmed.

Yet, the methodology in its present form shown a major limitation, in that the analysis considers as given (and, therefore, deterministic) the characteristics of the APS/SCM solution.

The output of the methodology is basically the result of a data collection and a data elaboration phase. While the calculation procedure is really accurate, more could be done regarding input acquisition. The interviewed managers happened to have difficulties in imagining the effect of an APS/SCM system on the way their company works: a possible extension of the methodology includes the development of a set of visual or numerical examples which will provided to the interviewees during the analysis.
Future research paths also include an extension of the methodology specifically developed to analyse the operations and the supply chain of service companies.

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Modeling of Supply Chain Contextual-Load Model for Instability Analysis

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1. Introduction

Simulation provides an alternative method for detailed analysis of the complex real world systems such as the supply chain. Given that a simulation model is well-suited for evaluating dynamic decision rules under 'what-if ' scenarios, a few attempts have been made to develop simulation models to improve supply chain performances. The modelling of supply chains dynamics adopted to simulation approach has been reported by many authors including (Towill *et. al.,* 1992), (Badri, 1999), (Bhaskaran, 1998), and (Sadeh *et. al.,* 1999).
More specifically, (Towill *et. al.,* 1992) used influence diagrams to visualise the cause-and-effect relationship between the decision rule and the improvement of supply chain performances. The main purpose of the study is to create a best decision rule that will allow the decision maker to reduce lead times, compress the distribution channel and co-ordinate information flow throughout the supply chain. (Bhaskaran, 1998) conducted a simulation analysis of supply chain instability. He shows how supply chains can be analysed for continuous improvement using simulation. The focus is on a stamping pipeline in an automobile supply chain based on operating data from General Motors. (Badri, 1999) developed a simulation-based decision-support system for multi-product inventory control management to enhance the competitive advantage of a furniture manufacturing firm using the simulation language SLAMSYSTEM and some statistical models. He claimed that the model allows managers to examine different inventory systems and policies without resorting to unrealistic assumptions and methods or having to use complicated mathematical techniques. (Sadeh *et.al.,* 1999) proposed an architecture that aims at providing a framework for coordinated development and manipulation of planning and scheduling solutions at multiple levels of abstraction across the supply chain. The architecture is configured around a blackboard architecture to allows for the easy integration of multiple planning and scheduling modules along with analysis and coordination modules.

Discrete-event systems (DES) simulation models are also a very popular approach for these types of problems. This simulation approach allows different combinations of decision strategies to be evaluated and thus provide adaptivity necessary for efficient use in dynamic, on-line environments. Compared with the previous DES tools for example GPSS, and SIMAN etc., the many sophisticated DES simulation packages available today, able to provide a more detailed simulation capability, even for real-time planning, scheduling and control, examples are ARENA, Witness, etc. (Terzi & Cavalieri, 2004) provide a comprehensive survey on over 80 simulation studies, how discrete-event simulation techniques could represent one of the main IT enablers in a supply chain context for creating a collaborative environment among logistics tiers. They establish which general objectives simulation is generally called to solve, which paradigms and simulation tools are more suitable, and deriving useful prescriptions both for practitioners and researchers on its applicability in decision-making within the supply chain context. The discrete-event simulation can be identified under two structural paradigms: local simulation paradigm, i.e., using only one simulation model, executed over a single computer, see for example, (Ingalls *et. al.*, 1999), (Jain *et. al.*, 2001) and (Lou *et. al.*, 2001) and parallel and distributed simulation paradigm, i.e., implementing more models, executed over more calculation processes using computers and/or multi-processors, see for example, (Gan & McGinnis, 2001), (Brun *et. al.*, 2002) and (Zulch *et. al.*, 2002). The methods to explore supply chain strategic decision support, production planning and distribution resources allocation, multi-inventory planning, and distribution and transportation planning have been reported for example in (Bottler *et. al.*, 1998), (Schunk, 2000), Promodel (Supply Chain Guru, 2002), and (Bagchi *et. al.*, 1998), respectively. However, the efforts of developing tools for decision support of adaptability to disturbances in supply chains are still lacking.

This work aims to answer a key question: what will be the dynamic behaviour of a particular parameter (example, the inventory level) in response to a change of a disturbance parameter value (example delay in delivery) at a different location in the system? The focus will be to study the effectiveness of the controller (decision policies) to provide stability under the presence of disturbances, as well as evaluating the effect of disturbances on the process (the supply chain system), and this is achieved via DES simulation.

There are various situations that could be addressed, but in this work, some of the questions to which answered are sought, are as follows:

- Will the system be able to adjust to *changes in product demand?*
- For example in situations where the lower echelon reduces orders, or increases orders.
- Will the system be able to adjust to changes in *manufacturing capacity*?
- For example in situations of machine breakdown.
- Will the system be able to adjust to *inventory disturbances*?

For example in situations where supplier provides incorrect amount of material.

Accordingly, the answer to this issue can be addressed through contextual load modeling. Meaningful analysis for revealing the complex behaviour of the supply chain system must consider modeling the system and its relation to its contextual components, that is, how the supply chain system would react to its environment. Such a model can be viewed as consisting of the supply chain model, made up of several components, together with its contextual components. These components are dynamic and are characterised by several variables, each changing with events and each linked through events to other variables.

Each of the particular situations of interest represents one contextual component of the complex system (the supply chain).
It is worth pointing out the difference between our method and other simulation models. Most of these methods, see (Badri, 1999), (Sadeh *et. al.*, 1999), and (Towill *et. al.*, Naim and (Wilkner, 1992), concentrate on issues like creating the best decision rule, but do not consider the complex relationships that occur if an upstream echelon fails to serve a downstream echelon. Ours, in common with for example (Bhaskaran, 1998), is focussing on analysing the supply chain instability. However, our approach allows detailed experimental set-up for example evaluating the effect of disturbances on the process (supply chain system) and addressing issues whether decision policies would provide stability in the presence of disturbances, see (Saad, 2003).
The chapter is organised as follows: section 2 discusses the supply chain system, and the inventory control policies researched. Section 3 summarises the design and development of the supply chain contextual load model, and describes the test model and procedures used. Illustrative examples demonstrating the applicability of the approach is presented in section 4. Section 5 gives the conclusions of this chapter.

2. The supply chain model description

A packaging industry supply chain description to be modeled via the contextual load modeling approach is given in this section.
The following main notation will be applied:

Notation	Description
x	Subscript indicating company x={A | B | C | D | E }
$_{ss}$	Subscript indicating steady state condition (example, $u_{Ess}(d)$)
i	Day of the week index ($i=0$ indicates Sunday), i=0,…,6
w	Week number index, w= 0, 1,…,W
d	Day number index (numbering starts from start of simulation) $d=(7w+i)$ *or*, d=0,1,…,D
e	Size of emergency order sent to printer
$I_x(d)$	Inventory level of printed labels at company x on day d
$p_x(d)$	Production at company x on day d
S_x	Order-up-to-level for company x
s_x	Re-order level for company x
ss_x	Minimum stock level for company x
$u_x(d)$	Order placed by company x on day d
$V_D(w)$	Average variation in weekly orders placed by company D measured at week w
$y_x(d)$	Goods delivered by company x on day d

Table 1 The main notation

Additional notation will be introduced as the need arises.
Figure 1 is a schematic diagram illustrating the relationship between the companies in the chain, the end product of which is the supply of boxes of fresh vegetables to a retailer.

Company A, the raw material supplier, supplies both paper and laminate to company B who produces rolls of blank labels. It is assumed that the adhesive is always available. Company B, the blank labels supplier, produces rolls of sticky labels (in customized sizes) from larger rolls of paper and adhesive. The blank substrate is supplied to company C, the label printer, who print, cut and supply label rolls to company D, the packer/filler. Company D is a large co-operative fresh produce company who, in addition to growing their own produce, purchase from a number of market gardeners and overseas companies. Company D packs and labels the product and supplies it to the distribution centre for company E, the retailer. Company E on receiving the ordering information from their stores will initiate the demand for boxes of fresh vegetables, and provides this information to company D.

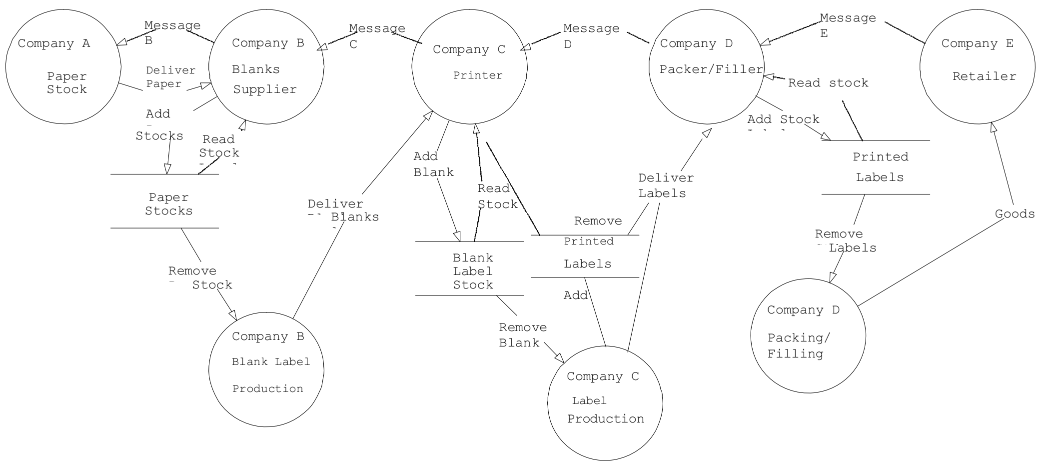

Figure 1. A schematic diagram of the packaging industry supply chain.

2.1 The model description

At steady state, assuming order from retailer (E) to packer/filler (D) equal $u_E(d)$. Packer/filler (D) uses a *generic policy* as the inventory policy to generate the orders. Minimum stock level for deterministic demand (safety stock level) at packer/filler equal ss_D. Re-order level at packer/filler $s_D = ss_D$ + LT x $u_E(d)$ units/day , where LT is the lead time equal three days. A weekly order from packer/filler (D) to printer (C) equal $u_D(d)$, and the order is sent on day, i = 0, that is Sunday. In addition to the weekly Sunday order, an emergency order, e, is sent if the stock level plus the quantity on order, falls to or below a threshold re-order level, $s_{D\ threshold}$.

This is expressed via the following inequality:

$$I_D(d) + \sum_{i=0}^{d} [y_C(i) - u_D(i)] \le s_{D\ threshold} \qquad (1)$$

where $s_{D\ threshold} = (S_D - (ss_D - u_E(d)))$

The emergency order, $e = 7^* u_E(w+i) - I_D(7w+i)$.

Printer company (C) can produce 100 units per hour and operates one shift of eight hours each day, i.e., maximum capacity of printer production equal 800 units. The delivery delay between printer (C) to packer/filler (D) is three days. It uses (*s,S*) *policy* for ordering blanks from blanks supplier. This inventory policy is very common in practice, see Silver & Peterson (1985). Order from printer (C) to blanks supplier (B) is sent if stock level plus quantity on order falls below s_C, units of blanks. In addition to the blank labels stock, there is also a buffer (intermediate) stock of printed labels in company C to hold some stock of printed labels. The quantity is typically between 100 and 200 units. The inventory policy is that sufficient labels are held in stock to meet needs of a sudden increase in order from packer/filler (D). The control decision is as follows: If buffer stock falls to or below 100 units, print $p_C(d)$=$y_D(d)$+100 units and add 100 units to buffer stock. If buffer stock is above or equal 200 units, print $p_C(d)$=$y_D(d)$-100 units and take 100 units from buffer stock. Blanks supplier uses (*s,S*) *policy* for ordering paper and substrates from raw material supplier. Order from blanks supplier (B) to raw material supplier (A) is sent if stock level plus quantity on order falls below s_B, units of blanks. Company A is assumed be able to provide a continuous supply of raw materials to company B.

2.2 Inventory control policies

The policies have been formulated based on observation of real-life process and also based on systems principles. The packer/filler company has access to information like the retailer's order, and the stock level at the packer/filler inventory. The packer/filler makes its own decision on how much to order by generating the order quantity based on the decision policy. The order generated by the retailer is issued directly to the packer/filler. No changes were made to the decision policies implemented at the printer company and the blanks supplier company.

The description of each policy at the packer/filler (D) is as follows:

a. Generic policy :

This policy is expressed heuristically as follows: A weekly order is placed with the order quantity equal to a weekly supply, or a seven day supply to retailer. An emergency order is placed on any day of the week if the stock plus the quantity on order declines to a lower limit called the re-order threshold point. The order quantity equals the difference between a weekly demand and the current stock. A closer look at this policy would suggest that it may be identified as the hybrid of the fixed size periodic review (fixed size of weekly order) and the continuous review (variable size of emergency order). The reviewing period is always scheduled for a particular day of the week as well as can be made at practically any day of the week. Detailed discussion on the periodic and the continuous reviews can be found in Hariga & Ben-Daya (1999) and Naddor (1966).

b. (s,S) policy:

This policy dictates that an order be placed when the stock declines to a lower control limit called the order point, *s*. The order quantity is the amount necessary to bring the inventory level to the order level, *S*. The (*s,S*) policy assumes continuous review. An emergency order is placed on any day of the week if the stock plus the quantity on order declines to a lower limit called the re-order threshold point. A more detailed discussion on the (*s,S*) policy can be found in (Silver *et. al.*,1998).

c. Pseudo PID policy:

The thrust of the idea for proposing this policy in this work comes from the control system representation and the use of feedback. Feedback has often had revolutionary consequences with drastic improvements in performance, see (Bennett, 1993). The PID controller is by far the most dominating form of feedback in use today and is used in wide range of problems, see (Astrom & Hagglund, 2001). An analogy to inventory control would be in the design of a controller that keeps process variables within range: a typical situation for level control in surge tanks where it is desired that the level changes but it is not permitted either to have the tanks flooded or to have them empty. Such use of PID type policy for inventory control is new and not available in the literature.

The operation of the pseudo PID policy is summarised as follows: An order is placed when the stock declines to a lower control limit, s, as described in the equations as given below. k_p, k_i, and k_d represent the proportional, integral, and derivative gains, respectively. The actual order is obtained from its desired value, after taking the physical limits of the inventory system and its dynamics. An emergency order, e, is placed on any day of the week if the stock plus the quantity on order declines to a lower limit called the re-order threshold point. As with the PID controller to improve steady-state error, the value of the order is adjusted accordingly using the expression representing the controller action.

The policies description given above are translated into their corresponding mathematical equations. The respective mathematical equations of the corresponding policies are as follows:.

a. Generic

$$u_D(7w+i) = \begin{cases} 7u_E(7w+i), & i = 0 \\ e, & i \neq 0 \end{cases} \tag{2}$$

b. (s,S)

$$u_D(7w+i) = \begin{cases} 7{*}u_E(7w+i) + [s_D - I_D(7w+i)], & i = 0 \\ e, & i \neq 0 \end{cases} \tag{3}$$

c. Pseudo PID

$$u_D(7w+i) = \begin{cases} k_p{*}7u_E(7w+i) + k_i\sum_{j=1}^{n}[s_D - I_D(7w+i+j)] + k_d[u_E(7w+i) - u_E(7w+i-1)], & i = 0 \\ e, & i \neq 0 \end{cases} \tag{4}$$

In the above, the value of e is computed, with $s_{D\ threshold} = (S_D - (ss_D - u_E(d)))$, as follows:

a. Generic policy

$$e = \begin{cases} 7u_E(7w+i) - I_D(7w+i), \text{ if } I_D(d) \le s_{D\ threshold} + \sum_{i=0}^{d}[u_D(i) - y_C(i)] \\ 0, \text{ if } I_D(d) > s_{D\ threshold} \end{cases} \tag{5}$$

b. (s,S) policy

$$e = \begin{cases} 7u_E(7w+i) + ss_D - I_D(7w+i), \text{ if } I_D(d) \le s_{D\ threshold} + \sum_{i=0}^{d}[u_D(i) - y_C(i)] \\ 0, \text{ if } I_D(d) > s_{D\ threshold} \end{cases} \tag{6}$$

c. Pseudo PID policy

$$e = \begin{cases} 7u_E(7w + i) - I_D(7w+i), \text{ if } I_D(d) \le s_{D\,threshold} + \sum_{i=0}^{d}[u_D(i) - y_C(i)] \\ 0, \text{ if } I_D(d) > s_{D\,threshold} \end{cases} \tag{7}$$

The main purpose of these policies is to act as a controller to countermeasure the disturbance due to fluctuations in the daily orders from retailer. The aim is to have a controller (decision policy) that keeps the process variable, that is, the inventory level within range. Basically, it is desirable that the inventory level changes but that it is not permitted to exceed a maximum level or be empty.

3. Contextual load model design

The contextual load modeling is conducted in this work with the realisation that meaningful investigation of a particular system, in this case the supply chain system, can be achieved by explicitly accounting for its environment. The task of developing the contextual load model would require the identification of the possible sources of disturbances that might exist in the system, the modeling of these disturbances and to decide the particular parameters in the model that is to be changed to simulate such disturbances. With this view, it is necessary to develop a general conceptual framework towards implementing a systematic and efficient representation of the contextual load model.

In this general conceptual framework, the orders (messages) can be regarded as feedback signals. The inventory (stock levels) is regarded as the controlled variable, CV. The measured value of the CV is transmitted to the feedback controller (decision-maker), and this controller makes a decision on the quantity to order or to be issued to the upper stage (echelon) based on the ordering policy (rules). The feedback controller (decision-maker) calculates the required amount to order based on the stock level, PV, and the ordering policy (rules). This value is reflected as the needed values of the manipulated variables, MV. The process represents the physical changes of the entities, for example, the process of transforming blank labels into printed labels, etc. Disturbance is any undesired change that takes place in a process which tends to affect adversely the values of the CVs, the input or the process.

On receiving an order from the lower echelon (retailer), the decision-maker at the packer/filler company will decide on when to start production, and at a specific time of the day will issue this information, as a MV (shows as MV_D) to the packer/filler production. Also, at some specified time of the day, the printed labels stock level is read. This information is used by the decision maker at the packer/filler company to decide on the size to order, the time to place an order, and perform the ordering. This is shown as u_D, or PV_C. This information is later used to calculate the required MV_C. Hence, the decision-maker at the packer/filler company is analogous to a feedback controller that performs the control of issuing orders and production, and regulates the stock level.

The same analogy also applies to the decision maker at the printer company. On receiving an order, u_D, from the lower echelon (packer/filler), the decision maker at the printer company will decide on when to start production, and at a specific time of the day will issue this information, as a MV (shows as MV_C) to the printer production. Also, at some point in time, the blanks labels stock level is read. This information together with the information from the printed labels stock (company C) is later used to calculate the required u_C, or PV_B. This information is then used by the decision maker at the blanks supplier (upper echelon), to calculate the required MV_B.

3.1 The sources of disturbances

Disturbance is any unwanted signal that corrupts the input and output of the plant or the process. The control system structure as depicted Figure 2 shows a detailed description of the system, including the disturbances.

The diagram of the system as depicted in Figure 2 underlies the identification of the disturbance types that may be present, namely: (a) The set-point (input) disturbance – designated as Type l disturbance, (b) The process (plant) disturbance – designated as Type ll disturbance, and (c) The control variable (output) disturbance – designated as Type lll disturbance. This selection correlates with the concepts from control system theory.

Table 2 summarises the disturbance types and their possible sources to be considered in the modelling of the contextual load model. As shown, the disturbances could have originated from a change in product demand (or variations of orders from retailer) – a Type l disturbance, change in manufacturing capacity – a Type ll disturbance, and also disturbance to inventories – a Type lll disturbance.

In this study, a changing operating point, and customer cancelling orders are two of the examples for Type l disturbance. An example for Type ll disturbance is in the event when machine breakdown occurs, while examples for Type lll disturbance includes stock wastage, faulty materials, late delivery, and supplier providing incorrect material.

Type	Disturbance	Sources of disturbances
I	Change in product demand	Changing operating points Customer cancel orders
II	Manufacturing capacity	Machine breakdown
III	Inventory disturbance	Stock wastage Faulty materials Late delivery Supplier providing incorrect material.

Table 2. Disturbances type and the sources of disturbances.

3.2 Modeling the disturbances

The objective of this work are to assess the effectiveness of each ordering policy in adjusting to changes in product demand, changes in manufacturing capacity, and inventory disturbances. The next task in developing a contextual model would require an understanding on how to model these disturbances and to decide on what particular parameter(s) in the model to be changed to simulate such a particular disturbance.

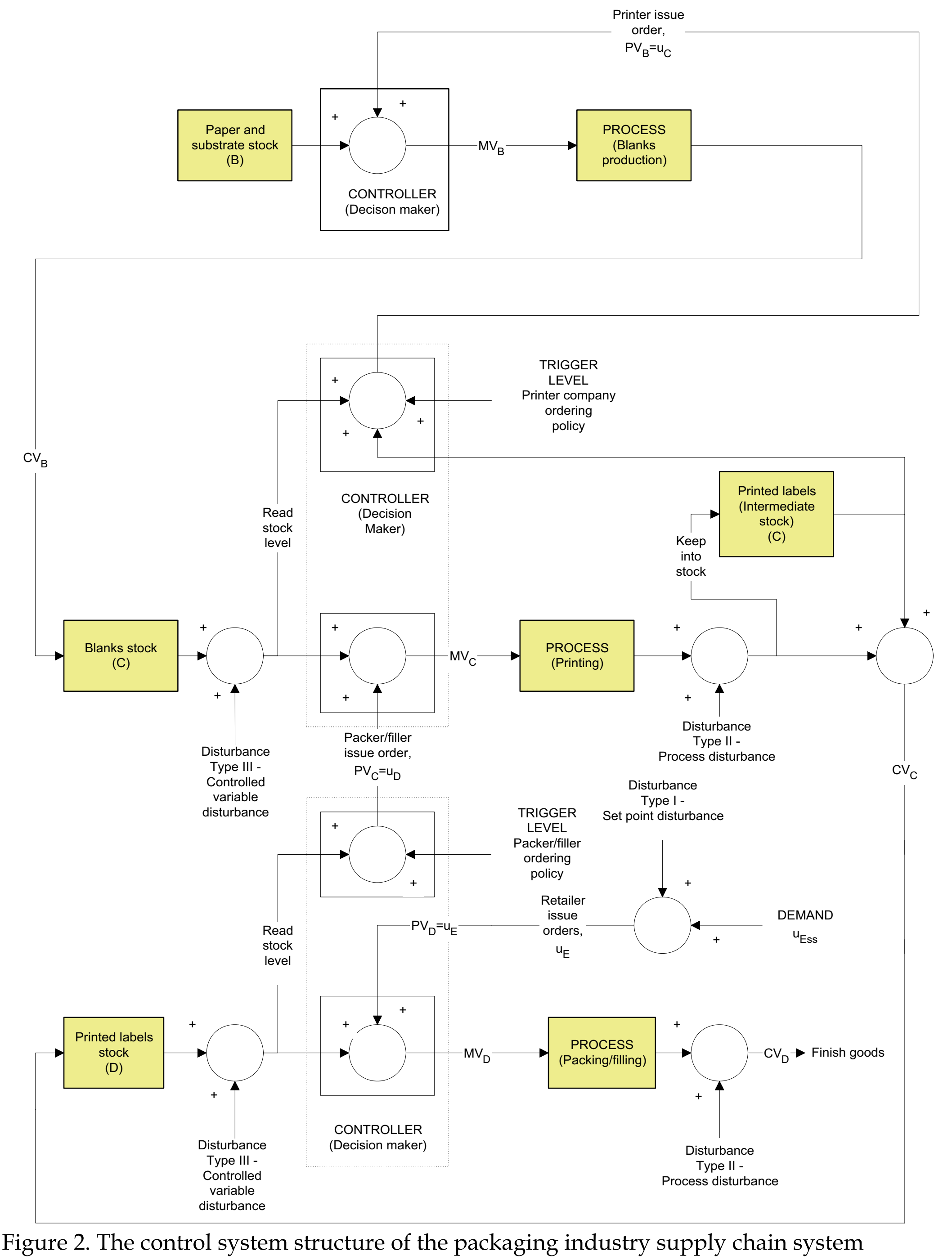

Figure 2. The control system structure of the packaging industry supply chain system

3.2.1 Type I disturbance: change in product demands

- *Changing in operating points:*

A variation in ordering pattern from the retailer will represent changes in product demands. For example, modelling this disturbance on the packer/filler company requires the model components to simulate an occasional change in the order quantity of retailer deviating from that of the usual demand due to product promotions and/or seasonal and trend factors.

- *Customer cancelling orders:*

The modeling of a cancellation of order is achieved by making the order quantity from retailer to drop to zero for that particular day.

3.2.2 Type II disturbance: manufacturing capacity disturbance

- *Machine breakdown at printer:*

Breakdowns can have a major effect on the performance of manufacturing systems. Many authors have discussed the proper modelling of breakdown (or downtime) data. These have been extensively discussed in Banks (1996), Williams (1994), Clark (1994), Law and Kelton (1991). Breakdowns can be deterministic or probabilistic in duration. Scheduled maintenance can be classified as deterministic. The breakdown is classified as probabilistic for almost all other circumstances. However, this requires either actual data for choosing a statistical distribution, or a reasonable assumption when data is lacking based on the physical nature of causes of downtimes.

In this study, two cases will be considered: (a) breakdown occurs before a regular order was made, and (b) breakdown occurs after a regular order was made. The following assumption is made regarding its implementation: failure is modelled to take place immediately upon the occurrence of a breakdown. Once the machine has been repaired it will continue processing the order that was interrupted when breakdown occurred, until completion. Any order that was received during the breakdown period will not be processed.

- *Faulty materials in printer:*

It is assumed that some portions of the material are damaged during the printing processes. This disturbance is modeled by treating that when packer/filler (company D) make an order of q units, the printer (company C) will print the amount as ordered. The production at printer will be q units, but due to faulty material the quantity delivered to packer/filler will be q units less the faulty.

- *Late delivery:*

This disturbance arises due to an unnecessary delay in the delivery of goods from printer company to packer/filler company. For example, late delivery may happen a few times during a certain period of time. The modeling of this disturbance is achieved by using a pure time delay block between the printer and the packer/filler.

- *Stock wastage in packer/filler:*

It is assumed that there are some percentage of material being damaged during transportation, or that material is scrapped due to changes in design format. In terms of disturbances, this would be reflected as an inventory disturbance, whose modelling has been discussed earlier in modelling the faulty material disturbance.

- *Supplier providing incorrect material:*

This disturbance assumes that the supplier provides material that is not the same as that ordered. For the system, it would be reflected as an inventory disturbance, and can be

modelled as in modelling the faulty material disturbance. However, the magnitude in this case would be large in comparison to the faulty material disturbance.
The creation of the relevant routines for the modelling will be addressed in section 3.3. The brief description on development of the simulation model, and the model verification and validation conducted will be given in sections 3.4 and 3.5, respectively. In section 4 the contextual model is utilised for several tests of "what-if" scenarios in the presence of disturbances. The purpose is to investigate how the various disturbances affect the behaviour of the supply chain system controlled by the inventory policies, and to give a qualitative characterisation of their performances.

3.3 Modelling disturbance routines

Some DES languages such as SIMAN, ARENA, and SIMSCRIPT have both process-oriented and event scheduling schemes capabilities, see (Cassandra & Lafortune, 1999). Notably, the event scheduling scheme capability would allow the programmer to control the logic flow (including the occurrences of events) in the simulation model. If the programmer has the flexibility to control the logic and events flow, then the implementation of disturbances could be realised by creating the appropriate routines. The approach to be described here is devised to create the DES routines for the modeling of the disturbances.
In order to implement the disturbances as specified in Table 4, the following steps have been taken.

a. Define a set of events at each particular resource. The resources refer to the inventories and production machines of interest.
b. Define a set of states for each resource.
c. Draw a DES sample path (a timing diagram with arrows with events denoted by arrows at the times they occur). A sample path can only jump from one state to another whenever an event occurs.
d. Indicate on the DES sample path the state at which the system would be, upon the occurrences of a particular disturbance. By using DES sample path to capture the characteristics of the resource, the desired behaviour of the resource when an unexpected disturbance occurs could be observed and understood.
e. Give a written implementation on DES, of modeling the particular disturbance.
f. Utilise ARENA modeling tools (modules) to implement the routines.

The DES sample paths developed in the modeling of the disturbances as listed in column 2 of Table 4 are as follows:

- Varying retailer's ordering patterns:

Define the set of events for the ordering as $E_{R\ order}$ = { Issue order equals Q_{nom} , Issue order above Q_{nom} , Issue order below Q_{nom} }
where,
Issue order equals Q_{nom} denotes the ordering of Q_{nom} , [e_1 in Figure 3]
Issue order above Q_{nom} denotes the ordering of above Q_{nom}, [e_2 in Figure 3]
Issue order below Q_{nom} denotes the ordering of below Q_{nom} , [e_3 in Figure 3].

Define the set of states for the retailer's as $X_{R\ order}$ = { Q_{nom} , Above Q_{nom} , Below Q_{nom} }
where,
Q_{nom} denotes the nominal quantity being ordered by the retailer , [x_1 in Figure 3]

Above Q_{nom} denotes the quantity being ordered by the retailer is above nominal , [x_2 in Figure 3]
Below Q_{nom} denotes the quantity being ordered by the retailer is below nominal , [x_3 in Figure 3].

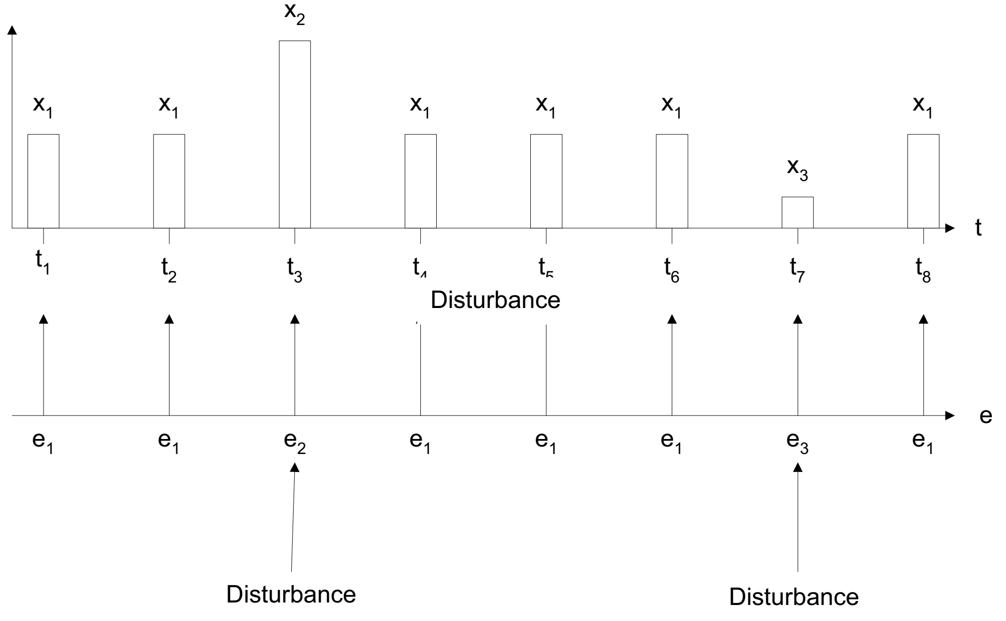

Figure 3. Sample paths for retailer's ordering pattern

The retailer's ordering pattern would be modeled to behave as follows: Whenever e_1 occurs, the state of the order would be x_1. This can be thought of as the system being in its steady state. For the case of disturbances, the state would be x_2 when e_2 is triggered, and if e_3 is triggered the state would be x_3. The triggering of event e_2 or e_3 would cause the ordering pattern to deviate away from the nominal values.
The routine for creating the retailer's ordering pattern would be as follows:
During no-disturbance, e_1, the state $x_1=k * x_1$, where k=1
Upon the occurrence of a disturbance, e_2, the state $x_2= k * x_1$, where k >1
Upon the occurrence of a disturbance, e_3, the state $x_3= k * x_1$, where k < 1
Example: The nominal order quantity is 100 units, hence for k=1 (during no- disturbance), the order is 100 units. To create a Type 1 disturbance (changing operating points) the value k is adjusted, say k=1.3, the order is 130 units, and if say k=0.8, the order is 80 units.

- Modeling machine breakdown

Define the event set for the machine as

$$E_{machine} = \{ arr_{mach}, dep_{mach} \}$$

where
arr_{mach} denotes an arrival of materials for production, [e_1 in Figure 4]
dep_{mach} denotes a departure of goods from machine, [e_2 in Figure 4].
Define the state for the machine as

$$X_{\text{machine}} = \{ B, I, D \}$$

where
B denotes that the machine is in the busy state, [x_1 in Figure 4]
I denotes that the machine is in the idle state, [x_2 in Figure 4]
D denotes that the machine is in the down (failure) state, [x_3 in Figure 4].
A DES sample path for this system is as shown in Figure 4.

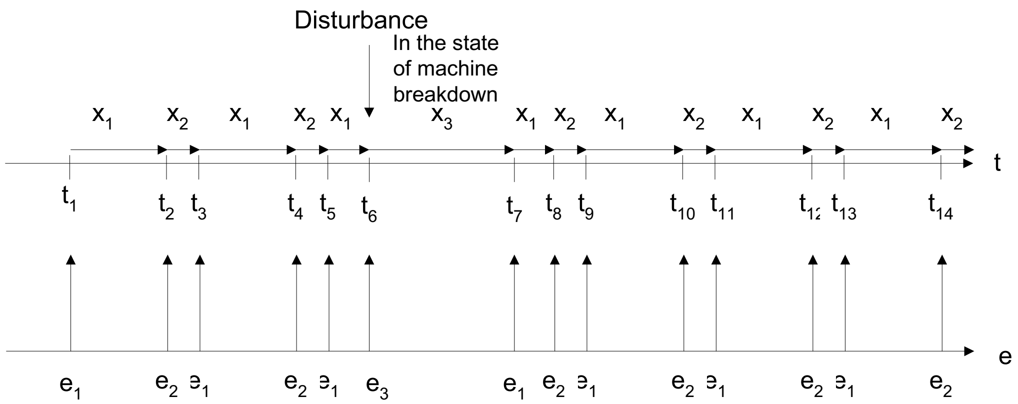

Figure 4. Sample paths for machine breakdown

The behaviour of the system would be as follows: Whenever e_1 occurs, the state of the resource would be x_1 (between t_1 and t_2 time interval). The state of the resource would be x_2 (between t_2 and t_3 time interval) when e_2 is triggered. Modeling this disturbance will amount to initiating event e_3 followed by the event e_1 after the time duration of machine breakdown. Upon the occurrences of a disturbance (the point of time when e_3 is triggered), as shown to be at t_6, the state of the packer/filler machine would then be x_3 (between t_6 and t_7 time interval).
Example: The modeler/programmer has the flexibility to create the occurrences of e_3. Say, e_3 occurs a day after a weekly order is issued, and the duration of the breakdown (the duration of time between t_6 and t_7) can be assigned as 3 days or 72 hours.

- Modeling faulty material

Define the event set for the printer production as

$$E_{\text{Printer}} \text{ production} = \{\textit{No faulty}, \textit{With faulty}\}$$

where
No faulty denotes the production batch is 100% acceptable, [e_1 in Figure 5]
With faulty denotes the production batch is with faulty, [e_2 in Figure 5].
The state of the printer production can be written as

$$X_P = \{ q \,,\, q \textit{ less faulty} \}$$

where
q denotes the production batch of printed labels (from printer company), [x_1 in Figure 5] q *less faulty* denotes the production batch with faulty labels, [x_2 in Figure 5].

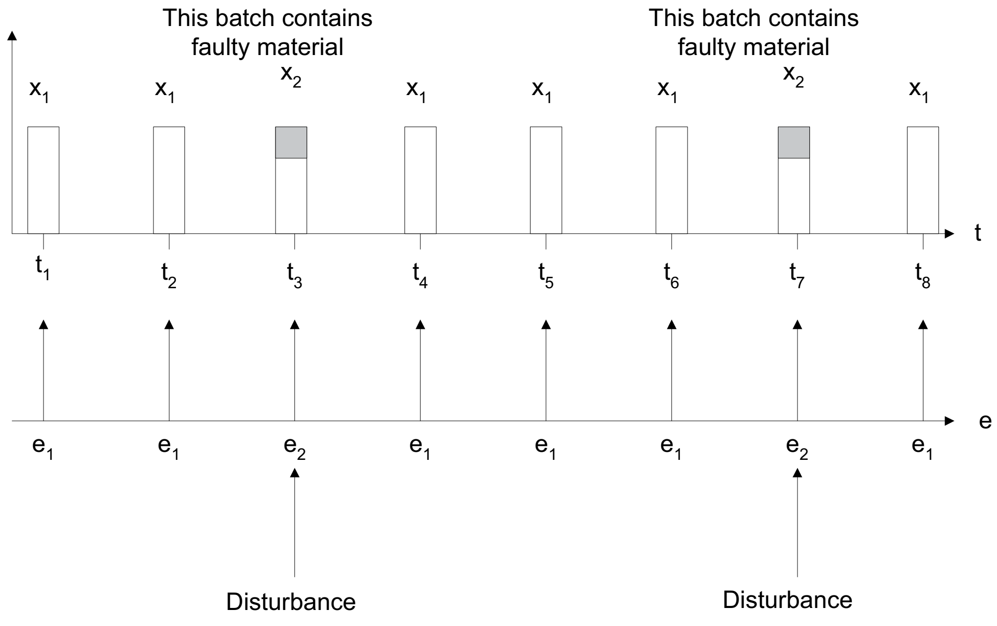

Figure 5. Sample paths for packer/filler printed labels stock

The sample path is as shown in Figure 5. The behaviour of the system should be as follows: Whenever e_1 occurs, the state of the resource (printer production) would be x_1. For the case when e_2 is triggered, the state would be x_2 where the shaded region indicates the portion of the production is faulty.

The routine for creating this disturbance would be as follows:

Upon the occurrence of a disturbance, the production at printer will be q units, but due to faulty material, the quantity delivered to packer/filler will be q units less the faulty.

Example: The modeler/programmer has the flexibility to create the occurrences of event e_2. For example, e_2 occurs and the batch being produced is assumed to have faulty material (assigned with a % faulty, say α). Upon completion, a portion that is assigned as faulty is disposed, and the other portion $(1-\alpha) * q$ is delivered to the next facility (company).

- Modeling late delivery

Define the event sets for delivery of goods as

E_{delivery} = {Start deliver goods, Deliver goods within normal time, Deliver goods longer than normal time}

where,

Send goods denotes the sending of the completed goods, [e_1 in Figure 6]

Deliver goods within normal time denotes the completed goods is delivered within time, [e_2 in Figure 6]

Deliver goods longer than normal time denotes the completed goods is delivered late, [e_3 in Figure 6].

Any goods delivered in less time will be considered as within normal time, since the range of time is still within the specified 3 days period and could not adversely affect the parameters being measured.
The states of the receiver (inventory) can be written as follows:

$$X_{\text{receiver}} \{ \text{Receive goods on time, Receive goods late} \}$$

where,
Receive goods on time denotes the completed goods arrives within normal time, [x_1 in Figure 6]
Receive goods late denotes the completed goods arrives late, [x_2 in Figure 6].

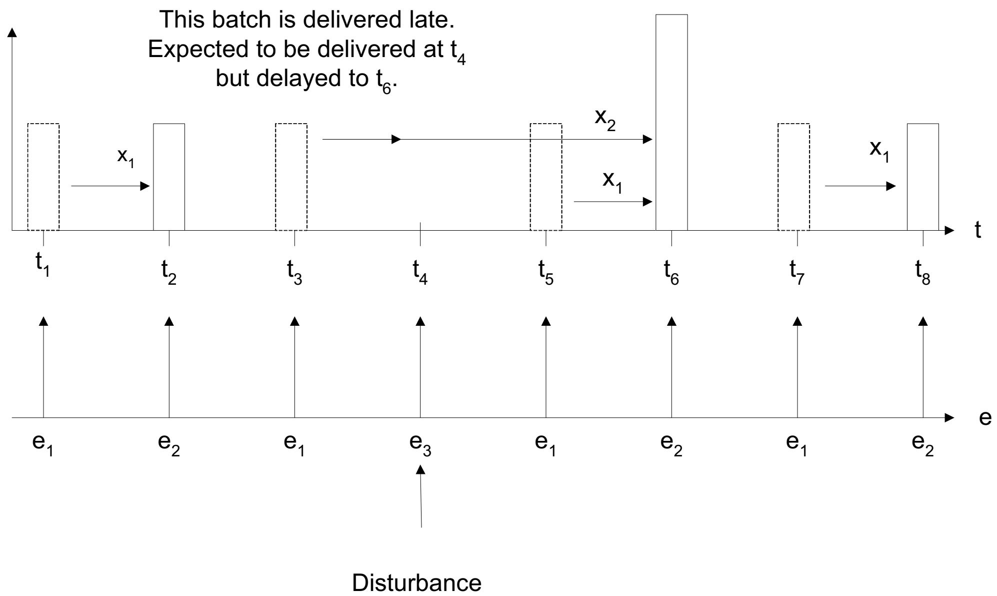

Figure 6. Sample paths for late delivery

The sample path is as shown in Figure 6. As an illustration, the behaviour of the system should be as follows: When e_1 occurs, the printer production will send the completed batch of goods to packer/filler. For normal delivery (event e_2), the goods will be received at the indicated time. For late delivery (event e_3), the goods will be subjected to additional delay time, t_{delay}. For normal delivery t_{delay} =0 hours. For late delivery t_{delay} = {24 (for 1 day delay), 48 (2 days delay), 72 (for 3 days delay), etc.}.
The routine for creating this disturbance would be to use a delay block between printer production and packer/filler inventory, where during normal delivery this delay would be zero (no delay), and positive non-zero otherwise (with delay).

3.4 Development of the simulation model

The design of the simulation model of the supply chain system is formulated as follows. The first step is to identify, express and modify the supply chain system directly in terms of its behaviour. The next step is to design the model according to the requirement that it will be utilised as an experimental tool to allow the study of some inventory and production control methods on the whole supply chain system. The following features have to be provided:

- Reading from an input file (for example, a text file) that will represent the order arrivals from the end customer.
- Writing output data to an output file (for example, Excel) for numerical and graphical representations of the variables of interest. These observations could then be analysed, and consequently the true system performance measures can be estimated.

The next following step is to define the mechanism to facilitate the coordination of the flow of products (materials) in an efficient manner with the use of messages. For instance, the controlling of the flow of system entities (products) could be addressed by manipulating the available order information (eg., the quantity to order) together with the information from each facility (eg., the inventory level) upon the occurrence of a certain event at a particular point in time. Finally, the next step is to adopt the concept of 'modularity', which is important for reducing the amount of time to build the implementation model .

A general coverage on how to carry out effective simulation modelling, analysis, and projects in ARENA environment can be found in Kelton *et. al.* (1998). The model is represented by a number of unique sub-models. These sub-models represent a central clock, an inventory facility, a production facility, the 'managerial unit' (logic decisions), an arrival of orders for materials, and a writing routine, as required in the complete model. The basic building blocks for each sub-model is developed using the modules templates in ARENA, for examples, the resources, systems entities, and delays. One of the main characteristics of ARENA modelling orientation is the use of the concept of entity-based, and process orientation. For this reason, the crucial step in the development of the implementation model is to successfully laying out the sequence of activities required to move the entity through the system, and supplying the data required to support these entity actions. Figure 7 illustrates the process chart representation of the implementation model. Nevertheless, it is not the intention of this paper to discuss in great detail on the building of the simulation model. More detail explanation can be found in Saad (2003).

3.5 Model verification and validation

The process of determining the correctness of model operation typically consists of two separate functions: verification and validation. Verification and validation activities is an on-going process throughout the modelling and simulation phases. A number of researchers including (Caughlin, 2000), suggested that whilst verification seeks to show that the computer program performs as expected and intended, validation, on the other hand, establishes that the model behaviour validly represents that of the real-world system being simulated. Both processes involve system testing that demonstrates different aspects of model accuracy.

One normally used technique is the *parameter variability-sensitivity analysis*. (Sargent, 2000), describes this analysis as follows. It consists of changing the values of the input and internal parameters of a model to determine the effect upon the model's behaviour and its output. The same relationships should occur in the model as in the real system. Those parameters that are sensitive, i.e., cause significant changes in the model's behaviour or output, should be made sufficiently accurate prior to using the model. A similar technique is used in the validation process for this work. Simulations were conducted to observe the effect of

changing the production rate at company C on the inventory levels of company C and company D, respectively.
In each case, the average entities' waiting times at these inventories were recorded. It shows that a reduction in the production rates, increases the average waiting time in the blank labels inventory of company C: implying that if company C were to reduce its production units per day, there would be some significant risks of stock-out in the inventory levels in company D. Simulations were also made to observe the effect of changing the production rate at company C on the percentage of orders filled (which should be maximized). The result suggests that the behaviour of the system does match the expectations of the behaviour of each element in the model. The results of the validation exercise is comparable to the available knowledge about the actual system.

4. Simulation results and analysis

This section will examine and analyse several "what-if" scenarios in the presence of disturbances against different policies. The number of possible scenarios are combinatorial in terms of possible disturbances and hence not all would be tested. Likewise, there are various types of inventory policies that could be tested, see (Silver *et.al.* ,1998). However, the investigation in this work will be focussing on the inventory policies discussed in section 2.
The detailed descriptions of the performance measures to be used for evaluation in this study is presented in Table 3. The performance measures have been defined for measuring the effectiveness and the efficiency of the decision policies. Different ordering policies will be applied at the packer/filler company and their performances will be analysed and compared.

Performance measures	Descriptions
Time to reach steady state	The ideal response of the packer/filler's inventory level to a step change in demand (retailer's orders) is that it should react as quickly as possible in adapting to the post step change level of demand, or to a new level.
Average stocks levels[a]	The inventory level is to be sustained at a low level.
Average variation in order quantity set to printer	The order variations should be kept small, since this can mean that the replenishments are made on a regular basis with small variations in the order sizes.
Number of emergency orders	The number of emergency orders is to be kept low, since this can mean that the extra cost incurred in the replenishments can be minimised.
Risk of stock out	Risk of stock out is to be kept low, since this reflects the ability to offer a reasonable level of service to the customer.

Table 3. Performance Measures, and Descriptions for the Model.

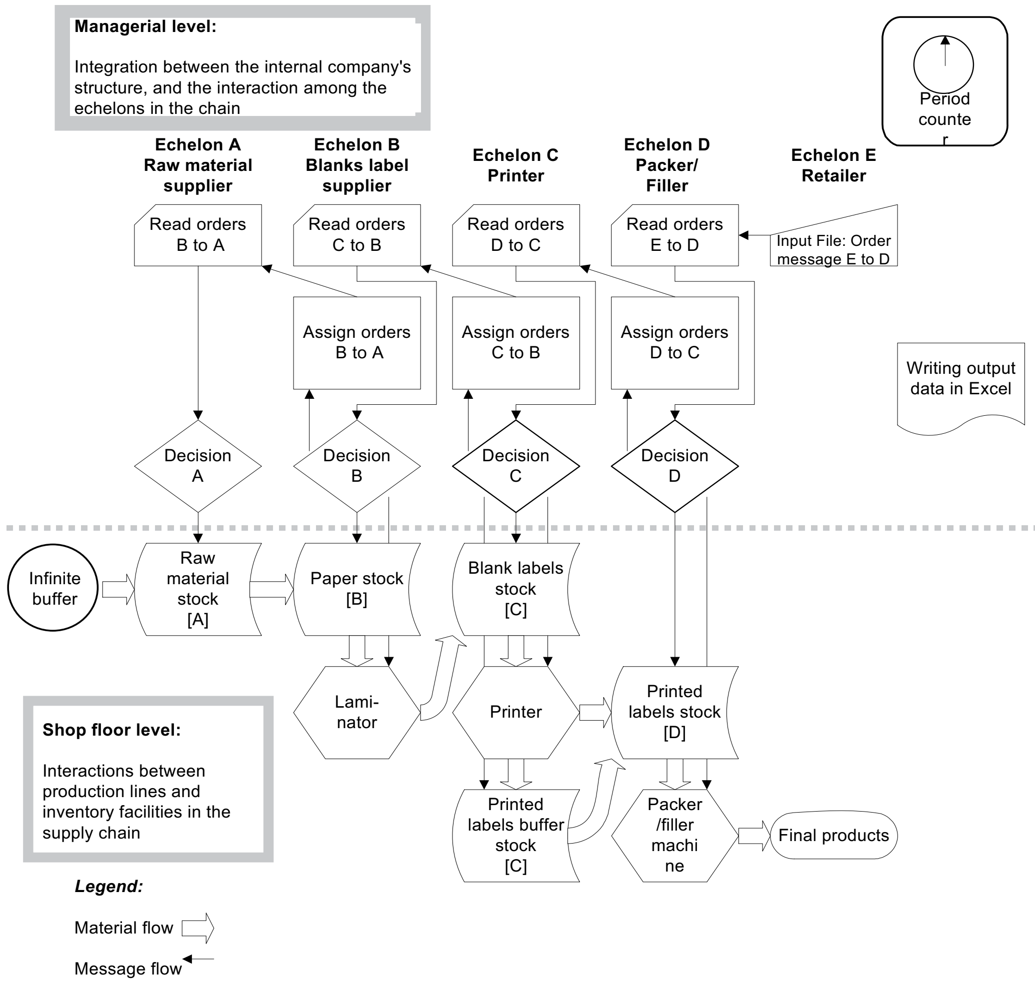

Figure 7. A process chart representation of the implementation model

4.1 Simulation example 1:

Type l disturbance - Changes in product demand

The simulation for Type l disturbance is to understand the consequences when those parameters that might be open to change in the future, particularly when the input patterns (retailer demand) were varied. The simulation presented here focuses on the pulse type of various magnitudes in the product demand from retailer, with the steps of the pulse being varied to +20%, +40% , +60%, +80%, and +100% of the normal demand (100 units per day). To compare the effectiveness of each policy in the presence of variations in the input pattern, two order policies (i.e. the (*s,S*) and the Pseudo PID inventory policies) were considered and the results were tabulated in Table 4. The (*s,S*) policy (test PD-a) is able to keep the number of risks down to zero, for most cases (pulse size 120 ~ 180). For the pseudo PID policy (test PD-b), the risks start to occur earlier (for pulse size 160 ~ 200). However, the (*s,S*) policy forces the packer/filler to keep comparatively large stocks: implying that having larger stock reduces the risk of stock-out. The results imply that the (*s,S*) policy is more robust than the Pseudo PID policy in keeping the risk of stock-out low if disturbances are in the form of larger product demand period. In this context, robustness implies that the policy is yielding performance that is insensitive to external disturbance and parameter variations.

	Order decision at packer/filler, u_D		
Input (Pulse demand pattern)	Output Performance	Test PD-a (*s,S*)	Test PD-b *Pseudo PID*
120 units *(+20% demand)*	Stock levels at packer/filler: l_{Dmax} l_{Dmin} *Risk of stock-out*	 1040 160 0	 990 200 0
140 units *(+40% demand)*	Stock levels at packer/filler: l_{Dmax} l_{Dmin} *Risk of stock-out*	 1120 20 0	 1080 100 0
160 units *(+60% demand)*	Stock levels at packer/filler: l_{Dmax} l_{Dmin} *Risk of stock-out*	 1380 120 0	 1170 0 1
180 units *(+80% demand)*	Stock levels at packer/filler: l_{Dmax} l_{Dmin} *Risk of stock-out*	 1460 60 0	 1320 0 1
200 units *(+100% demand)*	Stock levels at packer/filler: l_{Dmax} l_{Dmin} *Risk of stock-out*	 1600 0 2	 1500 0 2

Table 4. Comparison on the effectiveness of the decision (policy) in the presence of variations in the input pattern, based on the performance metrics.

4.2 Simulation example 2:

Type ll disturbance - Manufacturing capacity

The work presented here focuses on uncertainties during the occurrences of machine breakdown. Several performance metrics will be considered in making a comparison on the effectiveness of the different order decisions (inventory policies) at the packer/filler.

A decision-maker may want to know how these figures (performance metrics) change if the day of the breakdown is different. Specifically, the simulation will consider two cases: (a) breakdown occurs before the regular order is made (the effect of ignoring the regular order), and (b) breakdown occurs after regular order has been issued (if regular order is processed).

In all tests, the model was subjected to the same test conditions: simulation time of 60 days, machine breakdown period of 4 days (96 hours), and assuming a smooth demand from retailer (100 units per day). Performance results for the first case are displayed in Table 5a, and for the second case in Table 5b.

	Order decision at packer/filler, u_D		
Performance metrics	Test MB-1a *Generic*	Test MB-1b (*s*,*S*)	Test MB-1c *Pseudo PID*
Time to return to steady state (in days)	14	28	28
Average stock levels at D l_{Dav} ,and at C l_{Cav}	395 2928	655 2768	515 2796
Average variation in order quantity set to printer	60	160	94
Number of emergency orders, E at day *d*	1	1	1
Risk of stock out	2	2	2
Number of order batch undelivered	1	1	1

Table 5a. Comparison on the effectiveness of the decision (policy) in the presence of disturbance (machine breakdown occurs before regular order is made), based on the performance metrics.

	Order decision at packer/filler, u_D		
Performance metrics	Test MB-2a *Generic*	Test MB-2b (*s*,*S*)	Test MB-2c *Pseudo PID*
Time to return to steady state (in days)	14	28	49
Average stock levels at D l_{Dav} ,and at C l_{Cav}	620 2637	655 2632	615 2647
Average variation in order quantity set to printer	0	160	99
Number of emergency orders, E	0	1	1
Risk of stock out	2	2	2
Number of order batch undelivered	1	1	1

Table 5b. Comparison on the effectiveness of the decision (policy) in the presence of disturbance (machine breakdown occur after regular order is made), based on the performance metrics.

One can see that the tests for (*s,S*) policy (see Test MB-1b and Test MB-2b) show a similar output performance, indicating that even though the system is experiencing two different disturbances of machine breakdown, the effect will be the same throughout. This could suggest that the (*s,S*) policy provides good regulation in maintaining the stock. Tests for the generic and the pseudo PID show an increase in the average stock level of the packer/filler company, when a machine breakdown occurs after the regular order has been issued. Note that the lead times for all the tests (Test MB-1a ~ Test MB-1c, and Test-MB-2a ~ Test MB-2c) are assumed to be the same.

4.3 Simulation example 3:

Type lll disturbance - Inventory disturbances

In modeling this disturbance, the printer will print the amount as ordered, but the fault is modeled to take effect after the printing is completed. The argument is, if the printer production and delivery are kept separate, then this can be modeled more effectively. It is assumed that 20% of the order being delivered to packer/filler from printer to be faulty.

4.3.1 Type lll-Faulty material

The tests (Test FM-a ~ Test FM-c) assumed 20 % of material delivered from printer to packer/filler is faulty. The interest is focused on how effective the control schemes (inventory policies) are in regulating the system to the occurrence of the disturbance (faulty materials). The performance results are displayed in Table 6.

	Order decision at packer/filler, u_D		
Performance metrics	Test FM-a *Generic*	Test FM-b (*s,S*)	Test FM-c *Pseudo PID*
Time to return to steady state (in days)	14	14	42
Average stock levels at D l_{Dav} ,and at C l_{Cav}	519 2734	557 2737	546 2852
Average variation in order quantity set to printer	86	30	8
Number of emergency orders, E at day *d*	1	0	0
Risk of stock out	0	0	0

Table 6. Comparison on the effectiveness of the decision (policy) in the presence of disturbance (faulty materials), based on the performance metrics

Pseudo PID (see Test FM-c) is shown to reduce the average variation in order quantity set to printer. Although the time to return to steady state is relatively large (slow response), this may not be a disturbing factor considering that the average stock level at packer/filler is relatively low compared to the case with the (*s,S*) policy.

4.3.2 Type III-Late delivery

Two tests were performed. First test is a comparison on the effectiveness of each scheme (inventory policies) to the occurrence of late deliveries. The second is an analysis on the effect of the late deliveries that last for a certain duration of days, on the risk of stock-outs and to the number of undelivered items (batch ordered).

The first set of tests:

Table 7 compares the effectiveness of the different control scheme (inventory policies) to late deliveries, lasting 4 days. The summary of the findings is as follows: Tests LD-a, and LD-c indicate that the generic policy is effective in regulating the inventory at the packer/filler. The (*s,S*) policy (Test LD-b) can keep the average inventory level low, but the order issued to printer company is larger than the other policies. The Pseudo PID is slow to reach steady state, but performs well in other aspects of performance.

	Order decision at packer/filler, u_D		
Performance metrics	Test LD-a *Generic*	Test LD-b (*s,S*)	Test LD-c *Pseudo PID*
Time to return to steady state (in days)	14	28	63
Average stock levels at D l_{Dav} ,and at C l_{Cav}	770 2759	655 2632	690 2585
Maximum order quantity to printer, u_{Dmax}.	700	1400	810
Average variation in order quantity set to printer	100	160	147
Number of emergency orders, *E* at day *d*	1	0	1
Risk of stock out	2	2	2
Number of order batch undelivered	1	1	1

Table 7. Comparison on the effectiveness of the decision (policy) in the presence of disturbance (late deliveries, duration of 4 days), based on the performance metrics.

The second set of tests:

The analysis is on the effect of the late deliveries lasting a certain duration of days, on the risk of stock-outs and to the number of undelivered items.

Graph a of Figure 8, shows that for (*s,S*) policy, the risks of stock-out increases almost linearly from one (duration of 3 days of late delivery) to five (duration of 7 days of late delivery), and then settles to five (duration of 8 days onwards of late deliveries). For the pseudo PID policy, at first the risks emerges with just one (from duration of 3 days of late delivery) and then settles to two from duration of 4 days onwards of late deliveries. Graph b indicates that the number of undelivered items (ordered batch) were maintained with one for the pseudo PID policy. For the (*s,S*) policy the number of undelivered batch increases linearly and then stabilises to four occurrences from duration equals 7. The results indicate that the pseudo PID policies perform well in keeping the number of stock-outs low. On overall, results revealed the robustness of the various decision policies to the different types

of disturbances. In particular, it was seen that pseudo PID, a policy derived from the control system view point, exhibited much more robustness than other policies.
The model developed in this work was limited to the analysis of situations that have been discussed in this chapter. However, the modeling and simulation for other disturbances for example, the decision making at another company, for instance the printer company, would be similar and straightforward to what that has been presented.

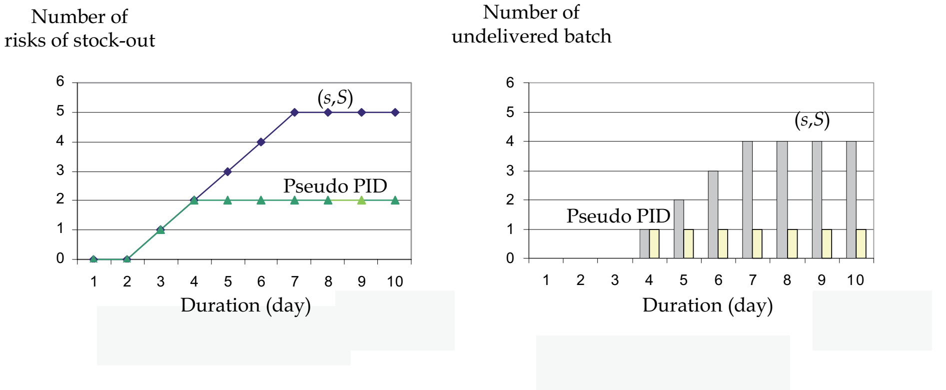

Figure 8. Risk of stock-outs and the number of undelivered batch for a specified duration of late deliveries. Graph a. Risk of stock-outs versus duration of late deliveries. Graph b. Number of undelivered items (batch ordered) versus duration of late deliveries.

5. Conclusion

Simulation using a DES is an effective tool for the dynamically changing supply chain variables, thus allowing the system to be modeled more realistically. The modelling, simulation, and analysis of a supply chain discussed in this chapter are a preliminary attempt to establish a methodology for modelling, simulation and analysis of a supply chain using a DES. There are further problems to be considered both in the development of the model and the experimental design.
The main contributions of this work are:

- As a DSS, the simulation model represents important characteristics of a packaging industry supply chain and incorporate the complex interactions that may exist between the various components in the system. Importantly, the model was designed with easily adaptable structure where rules (inventory policies) and model variables can be modified. By devising appropriate experimental design, several tests can be performed to imitate some realistic situations (the presence of disturbances). The results can then be analysed to provide information to a decision-maker from which solutions can be inferred.
- The detailed comparisons of three inventory policies (the *generic*, the (*s,S*), and the *pseudo PID*) for a production-inventory control under dynamic conditions were given. The *pseudo PID* policy, which has not been reported elsewhere, has been shown to have

several advantages as an inventory control policy. Qualitative behaviour of supply chain to different policies were confirmed through detailed quantitative analysis.

The future work should include:

- Development of a decision-support system for supply chain.
- Developing a decision-support system (DSS) software on the basis of the proposed approach with the consideration of more general and easy building blocks, and taking practical situation into account, would be beneficial. The particular emphasis should be given on development for a larger and demanding systems, such as multiple suppliers, and multiple customers (retailers).
- Verification and validation of the modelling approach.
- Applying the modelling approach to a different type of supply chain topology, in order to verify and validate the technique under different classes of systems will demonstrate the generality of the approach. The issue of verification and validation when real data are available has not been done here. If such data were available, integrating the method advocates in this work is with that based on real data would be an interesting paradigm in verification and validation.
- Modelling multiple disturbances.
- Although the *contextual load model* can simulate the complex behaviour of the supply chain from various scenarios, it is still not sufficient for most applications because the outcome of the analysis are based on the assumption that each disturbance occurs independently. The extension on the *contextual load* modelling, to understand how each controller (inventory policy) reacts to a combination of several disturbances (multiple disturbances), would still be required.
- Evaluation of inventory control policies.
- The evaluation of other inventory policies that already exist, and the modelling and evaluation of newly proposed inventory policies, for example new control theory motivated policies such as gain scheduling incorporated into the *pseudo PID* inventory control model, to provide insights and better understanding of each of the inventory control policy, would need to be explored.
- The work presented in this chapter has contributed to an improved understanding of the procedure for modelling, simulation and analysis of a supply chain system with a discrete-event simulation tool. Even though the approach presented here offers some promising tools, much work remains to be done to produce a systematic methodology for building a model of high complexity in nature, like the supply chain.

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25

New Measures for Supply Chain Vulnerability: Characterizing the Issue of Friction in the Modelling and Practice of Procurement

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1. Introduction

Supply chains consist of readily recognizable linkages, often between commercially distinct organizations that must coordinate activities to ultimately meet customer demand. Such organizations are not necessarily bound by a central planner who can both determine and dictate what procurement policies are implemented across these inter-organizational links. In the absence of such coordination, each organization can be expected to resolve procurement and replenishment policies from a local perspective, passing the demands of such to its suppliers in a highly intuitive, pull-style fashion. While such policies may seem reasonable to all partners involved and may be the only solutions tolerable from a political perspective, there exists the possibility that the decentralized policies are operating at a combined cost substantially higher than that which could be achieved through global optimization. The purpose of this chapter is to define this vulnerability and to suggest methods for anticipating it, both in the simulation modelling of supply chains and in practice

Efforts to characterize the vulnerability of inter-organizational links arguably predates the phrase 'supply chain'. As much of the early work on multi-stage inventory planning was being accomplished, Bowersox (1969) protested the inherent assumption of vertical integration in the formulation of many distribution problems, warning of inefficiencies that could arise in practice if, in fact, various stages represented distinct organizations. Working with small multi-stage networks, Schwarz & Schrage (1975) coined the phrase *system myopic* to identify policies in which inventory replenishment is planned locally, the connation of which implies potential weakness (the condition of near-sightedness) when conducted in a complex system. Nonetheless, supply chain literature has traditionally maintained what Otto & Kaab (2003) would later call the *operations research perspective*, relying heavily on the assumption that policies will be set by central decision-makers to optimize the performance of complex systems.

The reality of inter-organizational dynamics in supply chain management has gained greater attention in recent years, highlighted in the taxonomy of Wang (1995) as a *nexus of contract perspective* on operations. The supply chain literature survey by Stadtler (2005) cited globally dispersed inter-organizational chains as a challenge central to this field. Disparities between centralized and decentralized procurement policies for specific instances are being explored mathematically, such as for the relationship between a single retail outlet and its warehouse when demand for a particular product depends both on price and level of retail stock (Jørgensen & Kort, 2002), or for a single assembly operation supported by multiple suppliers each of which suffer uncertain component yields (Gurnani & Gerchak, 2007). To enable centralized solutions among independent organizations, i*nformation sharing* emerges as an important issue in this context, such as the work summarized in the survey of Huang et al. (2003). Given that an inter-organizational supply chain is structured such that all relevant information required to achieve a centralized solution is not reliably available, development of decentralized, negotiation-based schemes to approximate the benefit of the operations research perspective has received attention, such as the coordination processes developed for two-tier systems by Dudek & Stadtler (2007).

Yet surprisingly, practitioner surveys such as that of Armistead & Mapes (1993) have suggested confounding inconsistencies in the reported usefulness of intuitively beneficial mechanisms such as information sharing in practice. Some simulation studies modelling these issue have echoed this theme, such as the counter-intuitive findings of Lau et al. (2004), in which all stages of a simulated supply chain did not always need to be engaged in information sharing to achieve satisfactory system performance. Furthermore, it is not uncommon for studies modelling system-wide cost performance under various assumptions of information sharing and inventory management (for example, the serial inventory systems in Chen (1998)) to suggest the average superiority of centralized solutions to be as little as 2%. This has sparked debate as to whether such a gap is of any practical significance at all, such as the commentary of Hofmann (1997) and Aderohumnu et al. (1997) concerning the degree of improvement apparent in more centralized algorithms for solving a dyadic buyer/supplier lot sizing problem.

Wang et al. (2004) discuss further drawbacks inherent in the operations research perspective on supply chain systems, such as ignoring the facts that the cost of information processing for centralized planning may be expensive, the system may be too complex to readily identify optimal solutions, and that competitive behaviour between independent stages may exclude the use of such solutions even if available. Nonetheless, the paradigm of the central planner and the optimal solution is the pursuit the most efficient operation of the entire supply chain system, and each of the concerns outlined by Wang et al. (2004) could be addressed with effort and investment. Simultaneously, there exists ample evidence that the potentially costly interventions required to operate a decentralized system in a centralized fashion would not always result in profoundly better results. Gavirneni (2001) observes that the benefits of information sharing and central coordination appear to depend heavily on environmental factors such as the supply chain structure and its existing modus operandi, but there remains little insight from the current literature on precisely what these factors are and how they influence these benefits. This leaves unanswered the question that, in the presence of independent supply chain partners, *when* would a substantial effort to restore the operations research perspective of the system make a substantial difference in the system's performance? Can it be anticipated which supply chains will prove most vulnerable to inefficiencies induced by decentralized pull-style planning, distinguishing them from those for whom elaborate contractual arrangements and information sharing do little to improve performance beyond what is achieved through their own intuitive local optimization? These are the issues examined in this chapter, beginning with proposed measures for the degree of disparity between the quality of centralized and decentralized supply chain solutions, discussed as various forms of *friction* in the next section. Friction is a direct measure of the degree of benefit of the centralized planning of procurement between two or more supply chain stages. After discussion of the concept of friction in its general form in Section 2, mathematical formulations of friction in two-stage and three-stage systems with level, deterministic demand are developed in Section 3, so that these models may then be utilized in the simulation of 127,680 experimental instances, representing a broad range of environmental factors described in Section 4. Section 5 details the results of the simulation study, employing descriptive statistics, polynomial and logistic regression, and graphical representations to explore the intricate interactions of various factors in determining the relative robustness or extreme inefficiency of decentralized, pull-style planning. Section 6 provides further discussion and interpretation, including intriguing results such as those supply chain partners most vulnerable to higher system costs through decentralized planning are those partners most similar to each other in general cost structures and independent order cycle preference.

2. Proposed measures of supply chain vulnerability

To focus on potential vulnerability inherent in any inter-organizational supply chain arrangement, we introduce these five concepts:

- **friction**- the disparity between the cost of a decentralized solution and that of an optimal solution when conducting procurement across a supply chain structure. Friction represents the loss, if any, suffered by local optimization among otherwise independent supply chain partners. Friction is stated as a ratio of a decentralized to an optimal solution's value. Thus, it is assumed that friction can be no less than 1.0 for any given instance.
- **link friction**- friction observed between two partners, a buyer and a supplier.
- **chain friction**- friction observed in generalized supply chain structures consisting of three or more partner stages.
- **implicit optimization**- an environmental instance in which a supply chain structure suffers no friction. These are conditions under which local optimization results in solutions identical to the policies dictated by global optimization. Thus, implicit optimization is the equivalent of a value of 1.0 for the ratio friction.
- **economic blind spot**- an environmental instance resulting in extreme friction, so named because the independently operated supply chain partners fail to "see" the substantial savings associated with another solution. This is an alarming vulnerability that could potentially be anticipated by identifying the environmental factors associated with its occurrence.

Link friction and economic blind spots are simple to demonstrate. Consider the two-stage, dyadic structure pictured in the upper left-hand corner of Fig. 1, representing the partnership between a single buyer and supplier.

Consider a case in which the buyer consumes or distributes 210 units of the supplier's product each period, incurring a fixed cost of 200 to procure any number of units and paying 1.0 to hold one such unit in inventory for one period. The supplier incurs a fixed cost of 600 to replenish the stock at the level below, and 0.95 per unit per period in inventory costs. In decentralized planning, the buyer will prefer to order lot-for-lot, as it costs more to carry one period's worth of demand in inventory than it does to place a new order with the

supplier. With heavier fixed costs and somewhat lesser inventory costs, the supplier will then minimize cost by replenishing once every three periods.
Using a 12-period planning horizon as an example, the buyer will incur a total cost of 12 * 200 = 2,400, while the buyer would pay 4 * 600 = 2,400 in fixed costs and 4 * 598.5 = 2,394 in inventory costs. This results in a total system cost of 7,194, which is not an optimal solution in this setting. Despite the fact that this solution is highly intuitive to the two independent partners, the lowest cost solution dictates that both the supplier and the buyer replenish once every three periods. In this scenario, the buyer would pay only 4 * 200 = 800 in fixed costs but 4 * 630 = 2,520 in inventory holding costs, while the supplier would pay the same 4 * 600 = 2,400 in fixed costs, but hold no inventory after serving the buyer. The total combined system cost is only 5,720. This discrepancy between the two scenarios is expressed as link friction of 7,194/5,720 = 1.258, or a cost increase of nearly 26% attributable to decentralized planning, and a distinct economic blind spot in this partnership.
Now consider the same two-stage scenario, but with the following revisions: the buyer consumes or distributes 190 units per period (as opposed to the original 210), and the supplier's per unit, per period inventory holding cost is 0.55 (as opposed to the original 0.95). Now the solution arrived at through decentralized planning is identical to the optimal solution to this scenario: the buyer will prefer to replenish every two planning periods and supplier, supporting the buyer's consumption pattern, will replenish every four periods. This scenario represents implicit optimization, in that centralized planning can not improve upon the decentralized activities of two independent partners.

3. Formulation

3.1 Two-stage formulation

To express friction mathematically in the context of discrete, deterministic and level demand, consider the following definitions concerning the two-stage dyadic system illustrated in Fig. 1:
d = the per period external demand requirement.
h_i = the per unit, per period inventory holding cost at stage i.
s_i = the fixed cost of replenishment (ordering cost) at stage i.
T = the length of the planning horizon.
λ_1 = the order cycle length of stage 1, stated in periods.
λ_2 = the order cycle length of stage 2, stated as a multiple of λ_1.
At stage 1 we expect T/λ_1 order cycles within a planning horizon of T periods, with an implicit assumption that T/λ_1 is an integer. Likewise, we expect $T/(\lambda_1\lambda_2)$ order cycles at stage 2, and thus total ordering costs of the two stage scenario can be stated:

$$\frac{T}{\lambda_1} s_1 + \frac{T}{\lambda_1 \lambda_2} s_2 \tag{1}$$

For convenience, this expression can be consolidated into:

$$T \frac{s_1 \lambda_2 + s_2}{\lambda_1 \lambda_2} \tag{2}$$

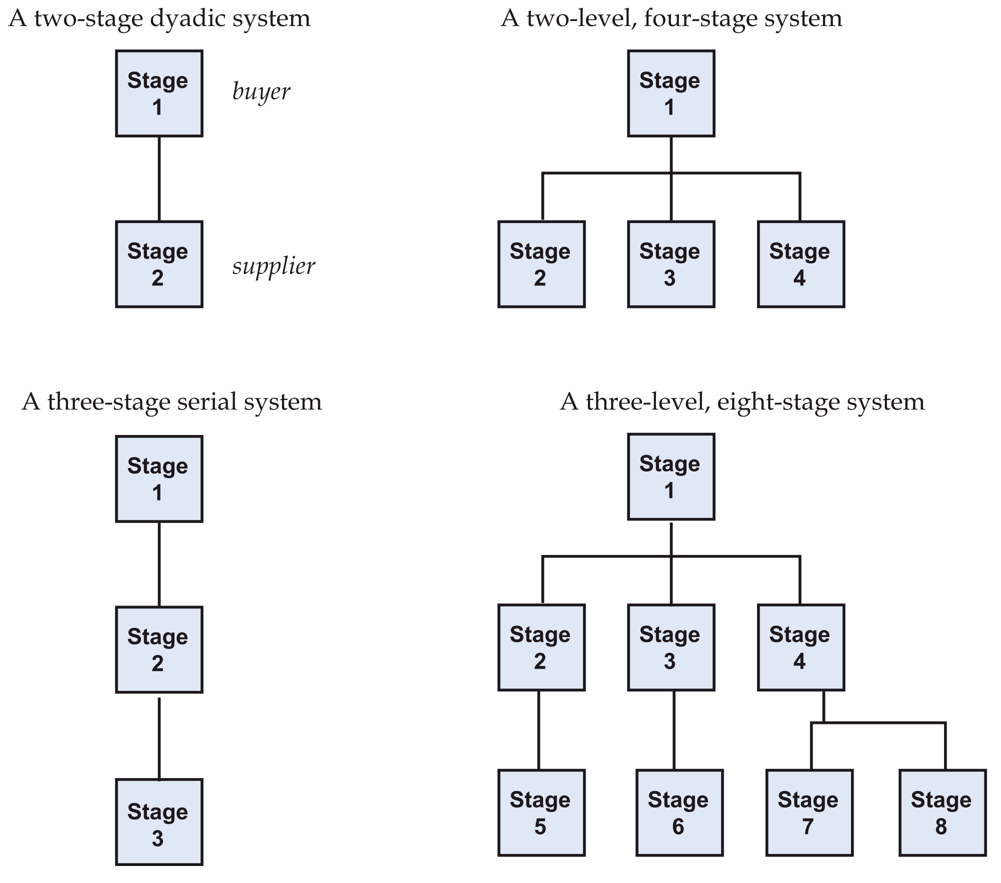

Figure 1. Four supply chain structures

To express the issue of inventory burden, consider the fact that each order cycle at stage 1 requires $d(\lambda_1^2 - \lambda_1)/2$ part periods of inventory, and thus each stage 2 order cycle incurs $\lambda_1^2 d(\lambda_2^2 - \lambda_2)/2$ part periods of inventory. Incorporating the respective holding costs and the number of order cycles yields an expression of the combined inventory holding costs for the two stages:

$$\frac{T}{\lambda_1} h_1 d(\frac{\lambda_1^2 - \lambda_1}{2}) + \frac{T}{\lambda_1 \lambda_2} h_2 \lambda_1^2 d(\frac{\lambda_2^2 - \lambda_2}{2}) \tag{3}$$

The latter half of expression (3) does assume a "one-to-one" demand relationship between the two stages; i.e. demand for d items from stage 1 results in the procurement of precisely d input items from stage 2. This highly convenient assumption can be made without loss of generality, in that any exception to this condition (i.e. two identical components are secured from stage 2 to support the provision of a single item for external consumption at stage 1) can be translated back into the former case by simply "kitting" the multiple components together and adjusting the associated holding cost.

$$\frac{Td}{2}(h_1(\lambda_1 - 1) + h_2\lambda_1(\lambda_2 - 1)) \tag{4}$$

Thus, the combined relevant cost of any policy of λ_1 and λ_2 can be stated as:

$$T\left(\frac{s_1\lambda_2 + s_2}{\lambda_1\lambda_2} + \frac{d}{2}(h_1(\lambda_1 - 1) + h_2\lambda_1(\lambda_2 - 1))\right) \tag{5}$$

To further simplify expression (5) and to highlight the roles of certain environmental cost factors that will later prove influential to the issue of friction, consider the following additional definitions:

p = the ratio s_2/s_1.

e = the ratio h_2/h_1.

$D = (dh_1)/2$.

Environmental cost factor p is an expression of the magnitude of the stage 2 fixed cost s_2 relative to the corresponding cost at the stage 1, or $s_2 = s_1p$. Similarly, environmental cost factor e allows the per unit per period holding cost at stage 2 to be stated in terms of the corresponding cost at stage 1, $h_2 = h_1e$. Introducing these relationships into expression (5) yields:

$$T\left(\frac{s_1(\lambda_2 + p)}{\lambda_1\lambda_2} + \frac{dh_1}{2}((\lambda_1 - 1) + e\lambda_1(\lambda_2 - 1))\right) \tag{6}$$

At this point, the introduction of factor D yields:

$$T\left(\frac{s_1(\lambda_2 + p)}{\lambda_1\lambda_2} + D((\lambda_1 - 1) + e\lambda_1(\lambda_2 - 1))\right) \tag{7}$$

To formulate the issue of link friction, it becomes necessary to discriminate between two policies, that which results specifically from decentralized planning versus an optimal policy with respect to minimizing expression (7). Therefore, we revise the definitions of order cycle lengths λ_1 and λ_2 to read:

λ_1 = the order cycle length of stage 1 which minimizes costs at stage 1, stated in periods.

λ_2 = the order cycle length of stage 2 which minimizes costs at stage 2 (given a value of λ_1), stated as a multiple of λ_1.

λ^*_1 = the order cycle length of stage 1 in a globally optimal solution, stated in periods.

λ^*_2 = the order cycle length of stage 2 in a globally optimal solution, stated as a multiple of λ^*_1.

Link friction, being the ratio of decentralized to optimal planning, can then be expressed as:

$$\frac{T\left(\frac{s_1(\lambda_2 + p)}{\lambda_1\lambda_2} + D((\lambda_1 - 1) + e\lambda_1(\lambda_2 - 1))\right)}{T\left(\frac{s_1(\lambda^*_2 + p)}{\lambda^*_1\lambda^*_2} + D((\lambda^*_1 - 1) + e\lambda^*_1(\lambda^*_2 - 1))\right)} \tag{8}$$

At this point we observe that link friction is essentially independent of planning horizon length T, and expression (8) can be simplified to:

$$\frac{\dfrac{s_1(\lambda_2+p)}{\lambda_1\lambda_2}+D((\lambda_1-1)+e\lambda_1(\lambda_2-1))}{\dfrac{s_1(\lambda^*{}_2+p)}{\lambda^*{}_1\lambda^*{}_2}+D((\lambda^*{}_1-1)+e\lambda^*{}_1(\lambda^*{}_2-1))} \tag{9}$$

The symbolic derivation of friction in a two-stage system now reaches an impasse, in that there exist no closed form expressions to further substitute for the order cycle factors λ_1 , λ_2 , λ^*_1 and λ^*_2, translating expression (9) into a statement of friction as a function solely of environmental parameters s_1, D, p and e.

3.2 Extensions of the two-stage formulation

3.2.1 Equivalent environmental instances.

Expression (9) demonstrates infinite environmental instances will share the same associated level of friction, due to the composite nature of the parameter D. Since D represents $dh_1/2$, a scenario in which s_1=100, p=2, e=0.5, h_1=1.0 and d=50 can be anticipated to have the same associated friction as a scenario in which s_1=100, p=2, e=0.5, h_1=0.5 and d=100, and so on.

3.2.2 General two-level supply chain structures.

Expression (9) not only represents an infinite number of environmental cases with equivalent link friction, this expression also calculates the *chain friction* associated with a special case of the generalized two-level structure, such as the two-level, four-stage system pictured in Fig. 1. In such a structure, the receiving level is populated only by stage 1, with the same parameters s_1, d and h_1 discussed early in Section 3.1. The supplying level, however, is populated by n stages numbered i = 2, … , n+1, each with an associated fixed cost of s_i and holding cost h_i, resulting in a potentially unique λ_i and λ^*_i for that stage. The combined fixed ordering costs of the system, the general two-level equivalent of expression (1), appears as:

$$\frac{T}{\lambda_1}s_1+\sum_{i=2}^{n+1}\frac{T}{\lambda_1\lambda_i}s_i \tag{10}$$

Likewise, the combined inventory holding cost of the two level system, the generalized form of expression (3), would be:

$$\frac{T}{\lambda_1}h_1 d(\frac{\lambda_1{}^2-\lambda_1}{2})+\sum_{i=2}^{n+1}\frac{T}{\lambda_1\lambda_i}h_i\lambda_1{}^2 d(\frac{\lambda_i{}^2-\lambda_i}{2}) \tag{11}$$

Similar to the arguments of Section 3.1, expressions (10) and (11) can be combined and simplified to yield the total relevant cost of the two-level system as:

$$T\left(\frac{s_1}{\lambda_1}+\sum_{i=2}^{n+1}\frac{s_i}{\lambda_1\lambda_i}+\frac{h_1 d}{2}(\lambda_1-1)+\lambda_1\sum_{i=2}^{n+1}\frac{h_i d}{2}(\lambda_i-1)\right) \tag{12}$$

Now consider a special case of the two-level system, in which the supplying stages are identical in cost structure. Thus, each second level stage incurs a particular fixed cost s'_2 and a particular per unit per period holding cost h'_2 associated with its replenishment cycles. Since each supplying stage likewise experiences the same level of demand from stage 1, all supplying stages would be observed to implement identical order cycles, in both decentralized (λ'_2) and globally optimal (λ'^*_2) planning of the system. Introduction of this condition into the general decentralized case represented by expression (12) yields:

$$T\left(\frac{s_1\lambda'_2+ns'_2}{\lambda_1\lambda'_2}+\frac{h_1 d}{2}(\lambda_1-1)+\lambda_1 n\frac{h'_2\, d}{2}(\lambda'_2-1)\right) \tag{13}$$

Following the definition of experimental factors p and e from the previous Section, let $p' = s'_2/s_1$ and $e' = h'_2/h_1$. Introducing the three factors p', e', and D into expression (13) yields:

$$T\left(\frac{s_1(\lambda'_2+np')}{\lambda_1\lambda'_2}+D((\lambda_1-1)+\lambda_1 ne'(\lambda'_2-1))\right) \tag{14}$$

At this point, it is apparent that expression (14) is the equivalent to the two-stage expression (7), for any $p = np'$ and $e = ne'$. Thus, expression (9) calculates not only the link friction between a buyer and a supplier stage, but likewise the chain friction between a buyer and n supplier stages with homogenous cost factors such that $p' = p/n$ and $e' = e/n$.

3.3 Three-stage formulation

Extending the formulation to three stages in serial formation (such as pictured in Fig. 1) is simply a matter of appending the third stage to the model in Section 3.1 with the addition of these factors:

λ_3 = order cycle length of stage 3 which minimizes costs at stage 3 (given a value of $\lambda_1\lambda_2$), stated as a multiple of $\lambda_1\lambda_2$.
λ^*_3 = order cycle length of stage 3 in a globally optimal solution, stated as a multiple of $\lambda^*_1\lambda^*_2$.

The logic behind defining the order cycle length of stage 3 as a multiple of $\lambda_1\lambda_2$ is that any stage's order cycle length is measured relative to the order cycle length of its *parent*, or buyer stage above. Stage 1 has no parent item to supply, the equivalent to an order cycle being imposed on it in the form of external demand is one period in length. In the decentralized case, total ordering costs for the system can be stated as:

$$\frac{T}{\lambda_1}s_1+\frac{T}{\lambda_1\lambda_2}s_2+\frac{T}{\lambda_1\lambda_2\lambda_3}s_3 \tag{15}$$

Each order cycle at stage 3 will require $\lambda_1^2 \lambda_2^2 d(\lambda_3^2 - \lambda_3)/2$ part periods of inventory. Thus, total inventory costs for T periods throughout the system is:

$$\frac{T}{\lambda_1} h_1 d\left(\frac{\lambda_1^2 - \lambda_1}{2}\right) + \frac{T}{\lambda_1 \lambda_2} h_2 \lambda_1^2 d\left(\frac{\lambda_2^2 - \lambda_2}{2}\right) + \frac{T}{\lambda_1 \lambda_2 \lambda_3} h_3 \lambda_1^2 \lambda_2^2 d\left(\frac{\lambda_3^2 - \lambda_3}{2}\right) \tag{16}$$

Expressions (15) and (16) can then be combined and simplified to create a model of total system cost analogous to the two-stage case in expression (5):

$$T\left(\frac{s_1 \lambda_2 \lambda_3 + s_2 \lambda_3 + s_3}{\lambda_1 \lambda_2 \lambda_3} + \frac{d}{2}(h_1(\lambda_1 - 1) + h_2 \lambda_1 (\lambda_2 - 1) + h_3 \lambda_1 \lambda_2 (\lambda_3 - 1))\right) \tag{17}$$

The earlier definitions of cost ratio factors p and e featured in the two-stage formulation in Section 3.1 must now be expanded to indicate which pair of stages the factors refer to. Now let:

p_1 = the ratio s_2/s_1.
p_2 = the ratio s_3/s_2.
e_1 = the ratio h_2/h_1.
e_2 = the ratio h_3/h_2.

Now the total three-stage system cost can be stated as:

$$T\left(\frac{s_1\left(\lambda_2 \lambda_3 + p_1 \lambda_3 + p_1 p_2\right)}{\lambda_1 \lambda_2 \lambda_3} + D((\lambda_1 - 1) + e_1 \lambda_1 (\lambda_2 - 1) + e_1 e_2 \lambda_1 \lambda_2 (\lambda_3 - 1))\right) \tag{18}$$

As with any other structure linking more than two stages, chain friction is understood to be the ratio of a decentralized versus an optimal three-stage policy:

$$\frac{\left(\frac{s_1\left(\lambda_2 \lambda_3 + p_1 \lambda_3 + p_1 p_2\right)}{\lambda_1 \lambda_2 \lambda_3} + D((\lambda_1 - 1) + e_1 \lambda_1 (\lambda_2 - 1) + e_1 e_2 \lambda_1 \lambda_2 (\lambda_3 - 1))\right)}{\left(\frac{s_1\left(\lambda^*{}_2 \lambda^*{}_3 + p_1 \lambda^*{}_3 + p_1 p_2\right)}{\lambda^*{}_1 \lambda^*{}_2 \lambda^*{}_3} + D((\lambda^*{}_1 - 1) + e_1 \lambda^*{}_1 (\lambda^*{}_2 - 1) + e_1 e_2 \lambda^*{}_1 \lambda^*{}_2 (\lambda^*{}_3 - 1))\right)} \tag{19}$$

3.4 Three-level extension of three-stage formulation

Analogous to the relationship between the two-stage and two-level system, the three-stage serial formulation can be shown to represent special cases of more general three-level models, such as the three-level, eight-stage system pictured in Fig. 1. Consider such a system, consisting of top-level stage 1, n second level stages numbered 2 through n+1, and m third level stages numbered n+2 through n+m+1. Let i^* represent the *parent* of stage i, also known as its immediate successor or its buyer. As with the two-level formulation, all second level stages have stage 1 as their parent stage, thus $i^* = 1$ for $i = 2$ through $n+1$. Expression (12), the total relevant cost of ordering policies in the context of a two-level system, can now be expanded to model three-level structures:

$$T\left(\begin{array}{l}\dfrac{s_1}{\lambda_1}+\displaystyle\sum_{i=2}^{n+1}\frac{s_i}{\lambda_1\lambda_i}+\sum_{i=n+2}^{n+m+1}\frac{s_i}{\lambda_1\lambda_{i^*}\lambda_i}+\frac{h_1 d}{2}(\lambda_1-1)\\ +\lambda_1\displaystyle\sum_{i=2}^{n+1}\frac{h_i d}{2}(\lambda_i-1)+\lambda_1\sum_{i=n+2}^{n+m+1}\frac{\lambda_{i^*}h_i d}{2}(\lambda_i-1)\end{array}\right) \tag{20}$$

Now assume a specialized structure such that stages 2 through $n+1$ on the second level have identical cost parameters h'_2 and s'_2, and thus identical associated parameters e'_1, p'_1, and λ'_2. Likewise, stages $n+2$ through $m+1$ on the third level are assumed to have identical cost parameters h'_3 and s'_3, and thus identical associated parameters e'_2, p'_2, and λ'_3. Following an algebraic progression analogous to expressions (13) and (14) in Section 3.2, the total relevant cost of this particular three-level assembly structure can be restated:

$$T\left(\begin{array}{l}\dfrac{s_1\left(\lambda'_2\,\lambda'_3+p'_1\,n\lambda'_3+p'_1\,p'_2\,m\right)}{\lambda_1\lambda'_2\,\lambda'_3}+D((\lambda_1-1)\\ +e'_1\,n\lambda_1(\lambda'_2-1)+e'_1\,e'_2\,m\lambda_1\lambda'_2\,(\lambda'_3-1))\end{array}\right) \tag{21}$$

Expression (21) is the equivalent to the three-stage expression (18), for any $p_1 = np'_1$, $p_2 = mp'_2/n$, $e_1 = ne'_1$, and $e_2 = me'_2/n$. Thus, expression (19) calculates not only chain friction for a three-stage serial system, but likewise the chain friction associated with a general three-level assembly structure with n second-level supplier stages with homogenous cost factors such that $p'_1= p_1/n$ and $e'_1= e_1/n$, and m third-level supplier stages with homogenous cost factors such that $p'_2= p_2n/m$ and $e'_2= e_2n/m$.

4. Computational experiments

4.1 Two-stage link friction test bed

The two-stage link friction test bed consists of 63,840 numerical experiments exploring the level of link friction concerning procurement between two simulated supply chain actors over a broad range of environmental factors. The policies associated with local versus central planning, (λ_1, λ_2) versus (λ_1^*, λ_2^*), are identified through line searches employing segments versus all of expression (7). Link friction, the outcome of interest, is then calculated with expression (9).

The size of the test bed is driven by the objective of testing each of the environmental factors required in the formulation of expression (7) over a broad range of values. Factor s_1, the fixed cost of replenishment associated with the receiving stage, is varied from 25 to 200 at intervals of 25, while the fixed cost ratio p ranges from 0.25 to 3.0 at intervals of 0.25. Holding cost factor e is tested at values selected from 0.05 to 0.95, at intervals of 0.05, and the factor D is tested from 25 to 220, at intervals of 5. Thus, 7 S_1 levels * 12 p levels * 19 e levels * 40 D levels = 63,840 experimental instances of link friction.

While the size of the 63,840 experiment test bed is intended to test friction levels over a broad range of environmental parameters, these 63,840 actually model an infinite number of scenarios of both link friction (as discussed in Section 3.2.1), and the chain friction associated with more general two-level structures with homogenous costs at the second level (as discussed in Section 3.2.2).

4.2 Three-stage chain friction test bed

The three-stage chain friction test bed consists of 63,840 numerical experiments exploring the level of chain friction between three simulated supply chain actors arranged in a serial configuration such as pictured in Fig. 1. In these experiments, factors p_1 and p_2, defined in Section 3.3, are assumed to be equal in value, and thus can be represented as environmental factor $p = p_1 = p_2$. Likewise, inventory holding cost factors e_1 and e_2 are set equal to each other, thus a single numerical factor $e = e_1 = e_2$ can be tested. The purpose of this assumption is to create a test bed design in which each of the 63,840 three-stage instances are directly analogous to a two-stage link friction instance. Thus, experimental factors p, e, D, and s_1 were all tested at the same levels described for the two-stage test bed in Section 4.1. In these experiments, the policies (λ_1, λ_2, λ_3) versus (λ_1^*, λ_2^*, λ_3^*), are identified through simple line searches employing expression (18). Chain friction is then calculated with expression (19). As with the two-stage test bed, these 63,840 experiments arguably model an infinite number of scenarios, including more general three-stage structures with the homogenous cost assumptions discussed in Section 3.4.

5. Numerical results

Simulation of the experiments described in Section 4 results in a total of 127,680 experimental instances of friction. Section 5.1 begins by outlining the summary statistics associated with friction levels observed within the two-stage and three-stage test beds. Section 5.2 follows with discussion of the results in terms of implicit optimization, or instances in which no loss is observed through decentralized planning. Section 5.3 explores the influence of the various environmental parameters on friction levels in general, and Section 5.3 focuses on typifying those observed instances of extreme friction, or economic blind spots, in particular.

5.1 Summary statistics

5.1.1 Two-stage link friction.

The 63,840 experimental instances in the two-stage link friction test bed exhibited an average friction of 1.03, as presented in Table 1. 42,277 of these instances, or 66% of the testbed, are examples of implicit optimization, in that an optimal solution to the experimenatal instance proved no better than a decentralized solution, resulting in a link friction of 1.0. However, embedded in the averages displayed in Table 1 are also 1,308 instances of link friction of at least 1.2. The maximum friction value observed was 1.317, indicating a 31.7% penalty in total cost incurred when the buyer stage plans first in that instance. Fig. 2 shows how friction, on average, responds to the ratio s_1/D, an environmental factor first shown to be significant in the earlier study by Simpson (2007). As parameter $D=dh_1/2$, the ratio s_1/D is the equivalent of $(2s_1)/(dh_1)$. Further interpretation of s_1/D will be discussed in later sections.

	s_1=50	s_1=75	s_1=100	s_1=125	s_1=150	s_1=175	s_1=200	Averag e
p=0.25	1.003	1.002	1.004	1.004	1.007	1.006	1.008	1.005
p =0.50	1.006	1.006	1.010	1.012	1.018	1.018	1.022	1.013
p =0.75	1.009	1.011	1.017	1.020	1.029	1.030	1.037	1.022
p =1.00	1.011	1.014	1.022	1.027	1.037	1.040	1.048	1.029
p =1.25	1.013	1.017	1.026	1.032	1.042	1.047	1.056	1.033
p =1.50	1.014	1.018	1.028	1.035	1.046	1.051	1.059	1.036
p =1.75	1.014	1.020	1.030	1.037	1.048	1.053	1.059	1.037
p =2.00	1.014	1.020	1.030	1.038	1.049	1.053	1.057	1.037
p =2.25	1.014	1.021	1.031	1.038	1.049	1.051	1.055	1.037
p =2.50	1.014	1.021	1.031	1.039	1.048	1.049	1.053	1.036
p =2.75	1.014	1.021	1.031	1.038	1.046	1.048	1.051	1.036
p =3.00	1.014	1.021	1.031	1.038	1.044	1.046	1.049	1.035
Average	1.012	1.016	1.024	1.030	1.038	1.041	1.046	1.030

Table 1. Link friction associated with two-stage test bed, n= 63,840 experiments

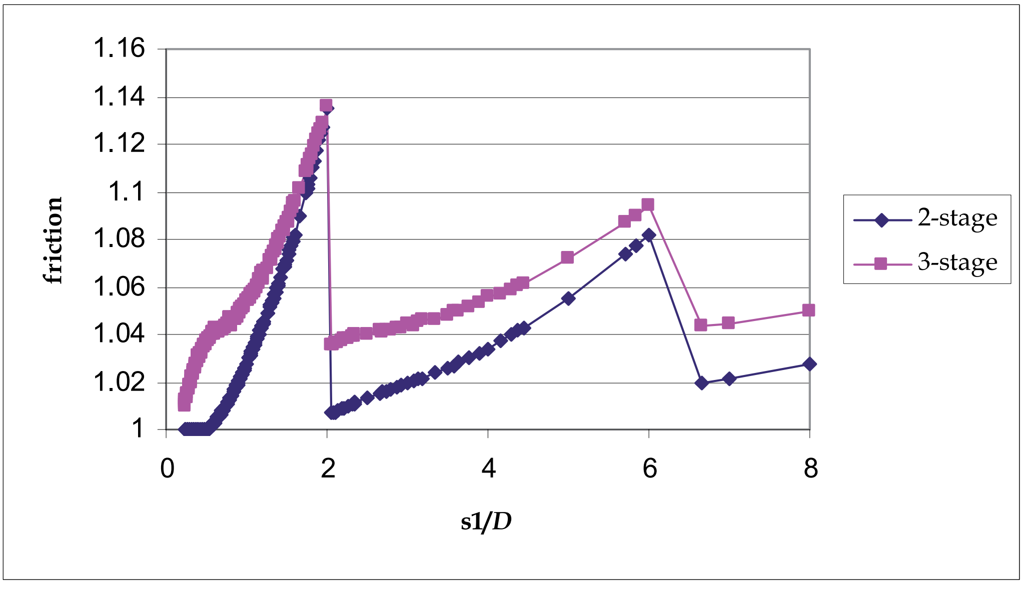

Figure 2. Interaction of link friction and the ratio s_1/D for two- and three-stage test beds.

5.1.2 Three-stage chain friction

The 63,840 experimental instances in the three-stage chain friction test bed exhibited generally higher friction than their two-stage counterparts, as is apparent in Fig. 2. Table 2 provides the summary of friction analogous to that provided for the two-stage cases in Table 1.

	s_1=50	s_1=75	s_1=100	s_1=125	s_1=150	s_1=175	s_1=200	Average
p=0.25	1.004	1.003	1.006	1.006	1.010	1.009	1.012	1.007
p =0.50	1.011	1.012	1.019	1.023	1.032	1.034	1.041	1.025
p =0.75	1.018	1.024	1.037	1.045	1.059	1.065	1.075	1.046
p =1.00	1.024	1.037	1.052	1.065	1.080	1.086	1.091	1.062
p =1.25	1.031	1.046	1.066	1.077	1.087	1.087	1.088	1.069
p =1.50	1.037	1.055	1.074	1.079	1.082	1.080	1.080	1.070
p =1.75	1.042	1.063	1.074	1.074	1.075	1.073	1.074	1.068
p =2.00	1.048	1.065	1.069	1.069	1.070	1.069	1.071	1.066
p =2.25	1.052	1.063	1.065	1.063	1.065	1.066	1.070	1.064
p =2.50	1.055	1.060	1.061	1.060	1.062	1.064	1.068	1.061
p =2.75	1.054	1.056	1.057	1.056	1.059	1.061	1.064	1.058
p =3.00	1.053	1.053	1.054	1.053	1.057	1.059	1.061	1.056
Average	1.036	1.045	1.053	1.056	1.062	1.063	1.066	1.054

Table 2. Chain friction associated with the three-stage test bed, n= 63,840 experiments

Only 26,627 experimental instances resulted in implicit optimization, or 37% less than associated with the two-stage test bed. Friction ranged as high as 1.466 in some instances, with 4,896 instances of at least 1.20, representing 7.7% of all experiments.

5.2 Anticipating implicit optimization

5.2.1 Two-stage test bed

To explore the factors associated specifically with implicit optimization, or the lack of friction, multivariate logistic regression analysis was employed to model that binary condition. Models associating the presense of implicit optimization with the various environmental factors as independent variables were run in SPSS with binary logistic regression (against the dependent variable of implicit optimization), using the Wald Forward selection method. This method selects only significant variables with the strongest correlation to the dependent variable. Pseudo r^2 values were then calculated to test the amount of variability explained and concordance and discordance measures were undertaken. As the full model displayed in step 5 of Table 3 indicates, every environmental parameter tested in this study is implicated in the issue of implicit optimization, although the majority of the explanatory power of this sorting scheme is captured in the smaller step 3 model relating implicit optimization to factors e, s_1/D, and p. As suggested by the findings, as of step 5, implicit optimization can be isolated within the test bed by calculating the logit of probability of friction, $-4.970 + .031s_1 + 1.000p + 5.932e - .033D - .602s_1/D$, for each experimental instance. A negative result predicts implicit optimization. 42,161 experimental instances return such a result, of which 87.7% of these are indeed instances of implicit optimization. The overall friction level of this group is only 1.006, although this model incorrectly indentifies 27 distinct economic blindspots, or instances in which friction was at least 1.20. The balance of the testbed, 21,679 instances, are assumed to involve friction, although 24.5% of these are likewise instances of implicit optimization misclassified by the regression equation.

	Step 1 Coeff.	**Step 2 Coeff.**	**Step 3 Coeff.**	**Step 4 Coeff.**	**Step 5 Coeff.**
Constant	-2.710*** [.067] (.024)	-4.216*** [.015] (.034)	-5.870*** [.048] (.003)	-7.357*** [.001] (.061)	-4.970*** [.007] (.067)
e	3.750*** [42.520] (.038)	4.415*** [82.722] (.043)	4.791*** [120.447] (.046)	5.033*** [153.455] (.048)	5.932*** [376.914] (.056)
s1/D		.763*** [2.145] (0.010)	.828*** [2.290] (0.010)	.633*** [1.883] (0.011)	-.602*** [.548] (.017)
p			.796*** [2.217] (.013)	.838*** [2.313] (.013)	1.000*** [2.718] (.015)
s_1				.012*** [1.012] (.000)	.031*** [1.031] (.000)
D					-.033*** [.968] (.000)
Model Chi Square	12125	20628	24890	27402	35473
Nagelkerke r-Square	.240	.383	.447	.484	.591
Model Significance	.000	.000	.000	.000	.000
% Implicit Optimization Correctly Predicted	82.8	86.0	88.6	88.9	89.4
% Instances of Friction >1 Correctly Predicted	44.1	54.6	61.7	64.9	71.8
Overall % Correct	69.7	75.4	79.5	80.8	83.4

Table 3. Results of forward stepwise (Wald) regression model of implicit optimization in two-stage test bed. Odds Ratio listed in square brackets[], with standard error in curved brackets(). *** Significance 1%

Despite the statistical significance of the full model, its associated r^2 is only 59.1%, a disappointing value from the perspective of predictive power. Furthermore, the logitistic regression equation itself is difficult to interpret in broad contextual terms. Nonetheless, this analysis, coupled with a series of graphical observations, suggests a simpler scheme for discriminating between instances of implicit optimization and friction. Approximately 65% of all instances of implicit optimization in the link friction test bed can be identified through the sequential application of three intuitive rules:

- **$s_1/D \le 0.5$**. This requirement identifies 10,260 experimental instances, each with a link friction of 1.0. $s_1/D \le 0.5$ implies that $s_1 \le 0.25dh_1$ indicating that the fixed cost at the first stage is no more than one-quarter the cost of holding a single lot of demand for one period. Restated, this rule identifies those instances in which fixed costs at the buyer stage are so small that the buyer's independent decision to order lot-for-lot is simultaneously the decision a central planner would reach.

- ***$s_1/D \le .990 - .458*\ln(p)$***. This requirement identifies 13,623 experimental instances (when applied after the first requirement), 7 of which have an associated link friction of 1.003 and the balance being perfect implicit optimization. This rule uses the factor $p = s_2/s_1$ to collect instances in which the environmental cost factors associated with the buyer are significantly greater than that of the supplier, thus there is little or no loss to allowing the buyer to dictate the plan.
- ***$s_1/D \le 1 - .507*e$***. Applying this requirement after the two rules identifies 3,527 experimental instances with an average friction of 1.0007, as 96% of this group represents implicit optimization. This rule reflects the distinctly linear inflammatory effect that factor e (the ratio h_2/h_1) has on friction.

Application of these three rules divides the link friction test bed into two groups: the 27,410 instances identified by the rules, 99.5% of which are examples of implicit optimization, and the 36,430 remaining instances possessing overall average friction of 1.052.

5.2.2 Three-stage test bed

As observed earlier, friction ran higher and implicit optimization was not as common in the three-stage chain friction experiments. Naïve application of the three rules developed to discriminate implicit optimization in the link friction case yields less impressive results when applied to the three-stage results: the analogous "implicit optimization group" of 27,410 experimental instances would be comprised of only 65% instances of implicit optimization and possess an overall average friction of 1.026, as opposed to the overall average of 1.00009 for its two-stage counterpart.

Employing multivariate logistic regression using the Wald Forward selection method to model implicit optimization in the three-stage data does reveal some insight, highly similar to the two-stage results detailed in Table 3. The resulting logistic regression equation in the three-stage case, logit of probability of friction = $-3.282 + .013\, s_1 + 1.149p + 4.389e - .013D - .221\, s_1/D$, sorts the test bed into a group of 29,050 instances of which 75.4% are implicit optimization, and a group of 34,790 instances containing only 13.6% implicit optimization. Like the previous two-stage model, this discrimitory ability, with its associated r^2 of 44.6% in the three-stage case, is surpisingly disappointing from the perspective of anticipating future occurances of implicit optimization.

In contrast, a tightening of the simplified two-stage rules developed out of the original two-stage regression analysis does yield additional insight into implicit optimization in the three-stage case. To discriminate between the majority of the instances of implicit optimization versus non-trivial chain friction in the three-stage test bed, apply the following three rules sequentially:

- ***$s_1/D \le 0.5$ and $s_1p_1/De_1 \le 0.5$***. 2,007 experimental instances fit this description, each exhibiting implicit optimization. These are environmental parameters such that both the first and second level stages have insubstantial fixed costs relative to inventory costs, and will be ordering lot-for-lot regardless of whether their schedules are decided independently or centrally.
- ***$s_1/D \le .337 - .587*\ln(p)$***. This requirement identifies 3,905 experimental instances with an average chain friction of 1.0003, 97% of which being examples of implicit optimization. This restriction identifies those experimental instances for which the relevant costs at the first level are substantially greater than those at the second and

third levels, thus "top-down" planning does little to damage system performance. Note that $p = p_1 = p_2$ in this test bed.

- ***$s_1/D \leq 2 - 3.889^*e$.*** Subsequent application of this cut identifies 11,396 experimental instances with an average friction of 1.003, as 75% of these instances represent implicit optimization. Note that $e = e_1 = e_2$ in this test bed.

Application of these three rules divides the three-stage chain friction results into two groups, the first being 17,308 instances with an average chain friction of 1.002, 83% of these being instances of implicit optimization. The balance of the chain friction test bed, 46,532 instances, now have an average friction level of 1.074, but 26% of these instances are likewise examples of implicit optimization.

5.3 Friction as a response to environmental parameters

5.3.1 The influence of the ratio s_1/D

Fig. 2 illustrates the distinct influence of the ratio s_1/D on the issue of friction in these supply chain structures, and this ratio has already proven invaluable to modeling much of the implicit optimization observed in the test beds. As discussed previously in Section 5.1.1, the ratio s_1/D can be restated as $(2s_1)/(dh_1)$. This breakdown of the ratio is useful when one considers that the worst cases of friction in both test beds, economic blindspots that implied up to 46% increase in system costs through decentralized planning, all occured when s_1/D was near or equal to a value of 2.0. Restated, average friction was peaking in Fig. 2 when $(2s_1)/(dh_1) = 2$, or $s_1/(dh_1) = 1$, or $s_1 = dh_1$. In other words, friction is observed to peak as the cost of holding one lot of external demand at the first level balances with the fixed cost of replenishment at that level. This is significant in that this represents a scenario in which the independent planner is logically *indifferent* to placing an order for that demand lot versus consolidating that requirement with the order for one period previously. In these simulations, it was assumed that, given indifference, the decision-maker would elect to place the additional order, acting on the general principle of avoiding inventory.

Fig. 2 suggests that friction peaks again to a lesser extent when s_1/D achieves a value 6.0, which implies $s_1 = 3dh_1$. Here the independent decision-maker at the first level is indifferent with respect to cost between a policy of ordering every two periods (λ_1=2) versus every three periods (λ_1=3), and thus is assumed to implement the former policy. An earlier, preliminary study in Simpson (2007) suggested further but lesser peaks when s_1/D neared values of 12 and 20, consistent with scenarios in which the first level decision-maker is economically indifferent between replenishing every third versus fourth period and fourth versus fifth period, respectively. However, Simpson (2007) also presents evidence that this intriguing influence is highly dependant on the condition of smooth demand, as modelled here. Intuitively, these points of indifference must be experienced repeatedly to induce the associated inefficiency, and highly dynamic demand with its resulting variable order cycle conditions rapidly mute the effect.

5.3.2 The influence of parameters *p* and *e*

Fig. 3 illustrates the average response of two-stage link friction to the two other environmental parameters observed to have profound influence on that test bed: the ratios p and e, representing the ratios of the second level to first level's fixed costs and holding costs, respectively. Each point in this surface represents the average friction for n=280 experiments across all factor levels of s_1 and D for given levels of p and e, and this response surface is very closely modeled by the expression z (average friction) = 1.0 +0.086e^2 + 0.002p^2 - 0.001p (r^2 = .843).

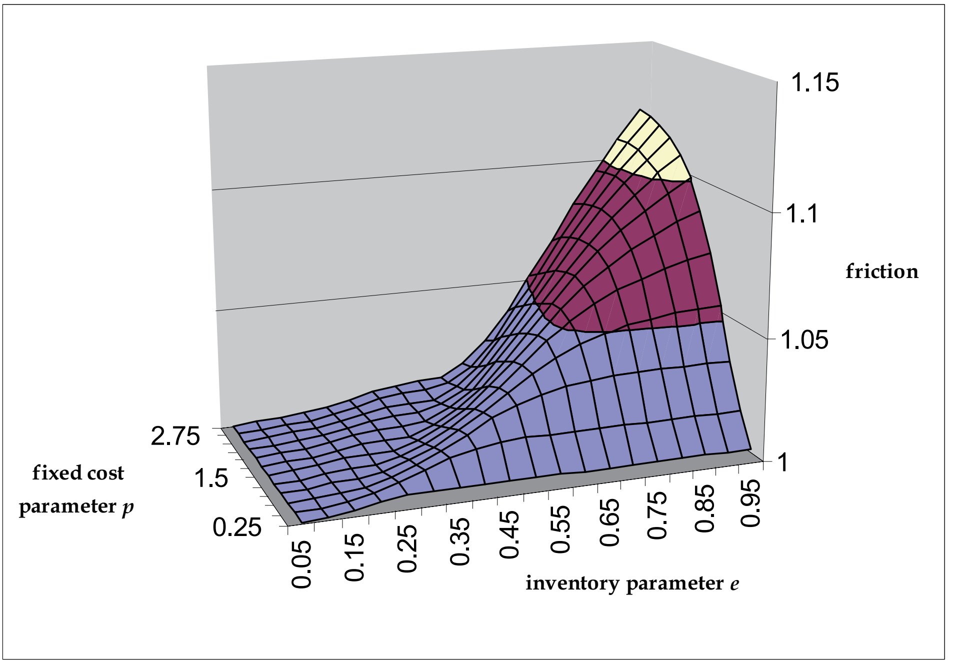

Figure 3. Response surface formed by average friction levels across environmental factor levels p and e for two-stage test bed.

Observation of the three-stage test results suggests similar relationships between these parameters and the broader effect of chain friction. In the case of the three-stage results, the response surface is closely modelled by z (average friction) = 1.0 + 0.351e^2 – 0.182e - 0.011p^2 + 0.043p (r^2 = .879). Furthermore, the *percent* increase between three-stage chain friction instances and their corresponding two-stage counterparts describes a highly similar response surface with respect to p and e, as shown in Fig. 4.

Further insight can be gained by looking at these two environmental parameters in isolation. Fig. 5 shows the distinctly "inflammatory" effect of the inventory parameter e: the higher the levels of this factor, the higher the observed levels of friction. Fig. 5 also indicates the intuitive result that this phenomenon is compounded by the addition of another level of planning, as the disparity between the average friction in the two-stage and three-stage experiments widens with increasing values of e.

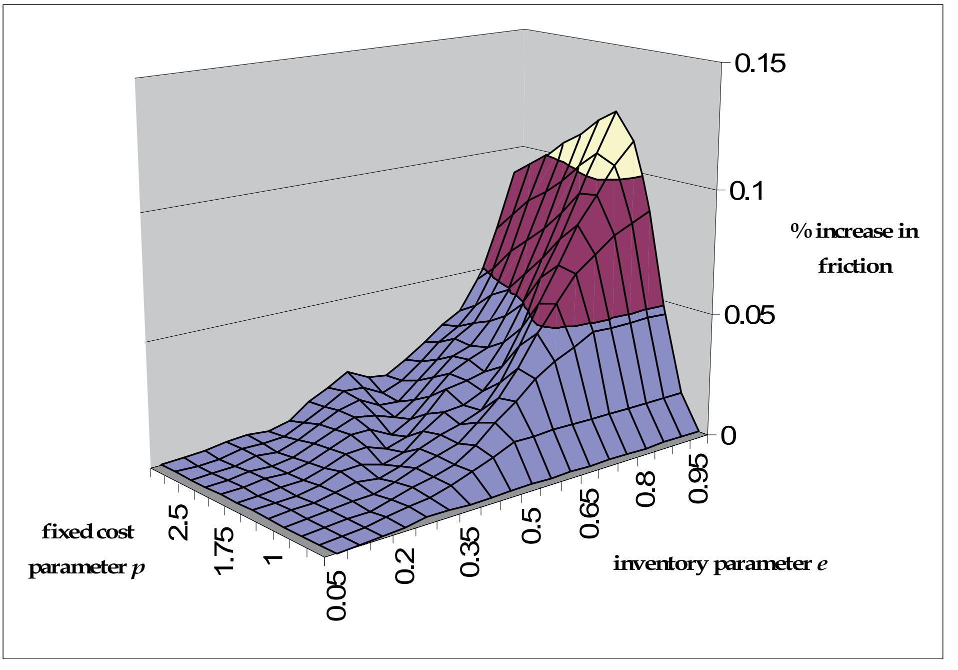

Figure 4. Response surface formed by average percent increase in friction levels when comparing three-stage to two-stage experimental instances, across environmental factor levels p and e.

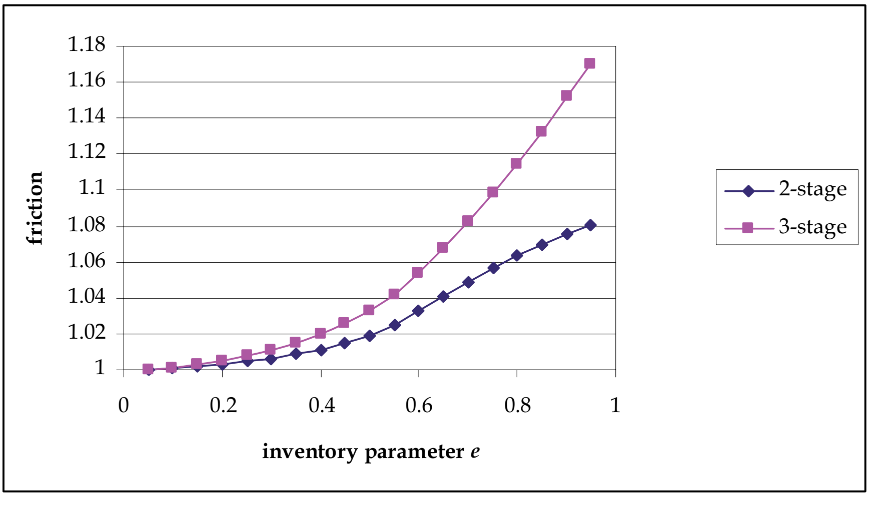

Figure 5. Average friction levels across factor level e for the two-stage versus three-stage results (n = 3,360 instances for each data point).

Fig. 6 illustrates average two-stage and three-stage response to the fixed cost parameter p, suggesting similar polynomial relationships with the issue of friction, but nonetheless in contrast with the ratio *e*. Unlike the inventory parameter *e*, the results do not support a strictly increasing relationship between parameter *p* and resulting friction. Rather, the highest average levels of friction witnessed on Fig. 6 are associated with the values of 1.5 and 2.0, and inspection of the data reveals that the absolute highest values of friction, or economic blind spots, are associated with somewhat lesser values of *p*, as will be discussed in the next section. Likewise, unlike factor *e* in Fig. 5, the disparity between the two-stage and the three-stage results does not appear to be strictly increasing with the value of fixed cost parameter *p*.

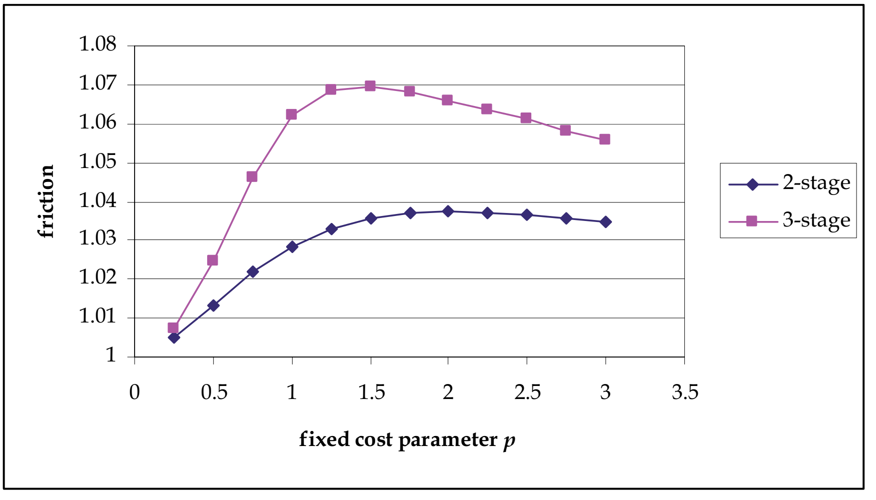

Figure 6. Average friction levels across factor level *p* for the two-stage versus three-stage results (n = 5,320 instances for each data point).

5.4 Anticipating economic blind spots

As discussed earlier, economic blind spots are so named because independent supply chain partners could potentially fail to "see" substantial savings achievable through centralized coordination. Interestingly, the findings in the previous section suggest these instances of extreme friction are associated with the same environmental parameters in both the two-stage and the three-stage test bed. In each case, the worst of the economic blind spots are confined to instances in which the following conditions occur simultaneously:

- $.75 \le p \le 1.25$
- $e \ge 0.9$
- $1.33 \le s_1/D \le 2.0$

These three conditions hold true for 282 experimental instances in each test bed. In the case of the two-stage test bed, average friction for this sub-group is 1.219 (in contrast to 1.030 for the entire test bed), containing of all instances of friction of at least 1.30. Within the three-stage test bed, average friction of these 282 instances is 1.310 (compare to 1.054 for all three-stage experiments), containing only 17% of the 880 three-stage experiments with chain friction of at least 1.30, but 100% of the 47 instances in which chain friction was at least 1.40.

6. Observations and conclusions

The results of this simulation study strongly suggest that certain inter-organizational supply chain partnerships could prove extremely vulnerable to the inherent inefficiency of decentralized procurement, while others could function quite comfortably in that mode, dependent on environmental factors. Thus, it is not surprising how, as discussed in Section 1, much of the existing literature exploring the relative merits of centralized planning and coordination reports distinctly mixed results. Indeed, it now becomes apparent how potentially dangerous it may be to draw conclusions from an average observation of interest in this context- the average loss from decentralized planning across these 127,680 experiments was only 4%, but this summary conceals the presence of distinct economic blind spots ranging as high as 46% increases in system-wide costs.

The new measures of link friction and chain friction discussed in Section 2 and the associated conditions of implicit optimization and economic blind spots assist in focusing attention on the relative merits of centralized planning, to rationally weigh these merits against any difficulties present in a given inter-organizational supply chain. Even in the context of the particular simplifying assumptions incorporated into the formulations of Section 3, resulting friction levels showed strong relation to both the environmental factors tested here, and complex interactions of those factors. The powerful influence of the cost factors p and e, both in the creation of instances of implicit optimization and in driving friction upwards, has interesting implications for simulation study design as well as practice. As an example, an earlier study of Simpson (2001) examined centralized versus decentralized procurement across a three level system of substantially greater complexity than the linkages modelled in Section 3, including features such as multiple products, joint order-picking costs, and time variant demand. Nonetheless, a highly centralized scheduling technique outperformed intuitive, pull-style planning by an average of only 1.8% across one group of 900 experiments, and yet this same technique lowered costs by an average of 31.5% within another group of 900 experiments. In hindsight, the only environmental difference between these two groups were the factors identified here as e_1 and e_2, these values being substantially higher in the latter case.

Section 5.4, outlining the environmental factor values most commonly associated with economic blind spots in both test beds, addresses the question posed earlier: *when* would a substantial effort to restore the operations research perspective of a system make a substantial difference in that system's performance? All three of the conditions identified in Section 5.4 have compelling interpretations. The first two, $0.75 \leq p \leq 1.25$ and $e \geq 0.9$, are indicating those experimental instances in which the fixed replenishment costs and the inventory holding costs of each of the supply chain stages are the *most similar to each other*. Restated, supply chains linking independent organizations with highly similar cost structures may see the greatest benefits from centralized interventions, or suffer distinct cost increases from independent behaviour.

However, to locate the most dramatic blind spots in this simulation study, Section 5.4 coupled the conditions of similar fixed and holding costs with a third condition, $1.33 \leq s_1/D \leq 2.0$. As discussed earlier in Section 5.3.2, the ratio s_1/D was found to be highly influential on the level of friction within a simulation, with the greatest degree of influence observed when this ratio's value was at or near a value of 2.0. This condition represents a scenario in which a buyer's fixed and inventory costs balance such that, when acting independently, this stage would be indifferent or nearly indifferent to recieving lot-for-lot replenishment versus replenishing two period's worth of demand requirements with each in-bound shipment. Thus, the presence of this condition of independent indifference to holding one period's worth of inventory based on cost (it is assumed that the buyer stage would otherwise favor no inventory simply on principle) strongly suggests that effort should be invested in identifying the centralized solution on behalf of system-wide performance.

As discussed earlier, there is evidence suggesting that the particular influence of s_1/D is not likely to hold beyond the conditions of level demand simulated here, in that these moments of indifference must be repeated through time to generate the inefficiency. Arguably, this is not as confining an assumption as it may first appear: supply chains supporting Just-in-Time (JIT) production will likely be supporting level production schedules, resulting in level procument patterns across in-bound partnership links. Furthermore, as pointed out by Gavirneni (2001), much of the recent re-engineering of supply chain partnerships has been in support of JIT inventory management. Thus, the issues of characterizing and identifying those supply chain relationships most vulnerable to decentralized treatment should not be considered simply a promising direction for further research, but a genuine and on-going need in the successful management of the increasingly complex systems observed in the field.

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26

Competence Based Taxonomy of Supplier Firms in the Automotive Industry

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1. Introduction

In the last 15-20 years companies went through a series of heavy economic blows in Hungary: first, the paternalistic state disappeared and they had to start to manage themselves and their own capital. Second, the collapse of the Russian industry forced most of them to find new markets for their products in order to survive. Third, the accession to EU brought competition much closer to them than ever before. Although a lot of companies disappeared during these years and even more were founded, we can say, that they have to improve themselves continuously to adapt to the changing conditions in order to remain competitive. Thus competitiveness is and was a focal issue in the Hungarian economy.

Today, with the accession to EU, the key to competitiveness for Hungarian companies is to what extent they are able to join European or even global supply chains. How can they discover the requirements of various customers and how can they improve their internal operations to fit these requirements? These are very general questions, but the answers are different company by company. We believe, however, that there must be some general patterns behind the scene, which might be useful for companies to know how to position themselves in the supply chain.

Several OEMs have started business in the automotive industry in Hungary and in the neighbouring transition economies providing chance for Hungarian suppliers to join their supply chains. Furthermore, due to the intense global competition and the matured stage in the life cycle in automotive companies supply chain management practices are vital. That is why we selected this industry as the basis of our research.

We believe that similarly to portfolio models which segment suppliers, we can build taxonomy on various customer values and supplier competences. Our paper discusses this focal question by using a general model of competitiveness for a series of interviews from the Hungarian automotive industry. In this paper we concentrate on the competence side of the model and use interviews as an empirical base.

The structure of our paper is the following: first we go through the relevant literature. Next the model of competitiveness and our research method is introduced. Then we describe the cases shortly and analyze the information we got. Finally our taxonomy is developed and conclusions are drawn.

2. Literature review

Firm competitiveness, as defined by Chikán et al (2002) is "the basic capability of perceiving changes in both the external and internal environment and the capability of adapting to these changes in a way that the generated profit flow guarantees the long term operation of the firm". Firm competitiveness in this broad understanding is basically a function of two factors (Gelei, 2004): customer value and core competences.

Customer value is defined from a customer point of view. It includes the aspects that are important for the customer in relation to the supplier. Since customer value is a very broad term, researchers usually split it into different dimensions. The most accepted approach in operations management is to speak about value dimensions as sources of competitiveness (Chase, 2001), such as price, quality, flexibility, reliability or service. Important to emphasize that these dimensions are identified from a customer aspect by the supplier answering the question what the customer wants from me. There are less well-known approaches, however. Their common feature is the supplier aspect they use. Mandják & Durrieu (2000), for example, group value dimensions on transaction, partnership and network levels. They argue that customer values are different when suppliers simply fulfill transactions, when they have to manage their partners or when they have to manage a whole network of companies. Walter et al (2001) speaks about direct and indirect value dimensions. Direct value dimensions are formulated through direct partnerships, while indirect value dimensions are realized beyond the given partnership involving other business partners. For example, volume dimension is a direct value dimension, which refers to the volume generated by the given customer, providing for the supplier to reach the breakeven point. Market dimension, on the other hand, is an indirect value dimension providing reference for the supplier leading to further market opportunities and orders from other customers. Finally, Möller & Törrönen (2003) use the dimensions of efficiency, effectiveness and network. Efficiency relates to the supplier's financial, profitability aspects, effectiveness relates to customer requirements and satisfaction and network relates to partners and wider stakeholders.

In our opinion value dimensions are elements through which value generation for the customer can be realized. Customer values are defined by the customers (consciously or unconsciously) and suppliers have to understand these values in order to provide a product and service package which customer expects and respects.

The second factor of firm competitiveness is the sum of resources and capabilities that makes a firm able (capable) to create and deliver what is expected by the customer.

The resource based theory of the firm (Penrose, 1959; Wernerfelt, 1984) and, inspired by their views, the resource based strategic management (Hamel – Prahalad, 1990, Grant, 2001) interprets firms as complex sets of resources and capabilities and considers them as the source of firm competitiveness. Although we are aware that there are other approaches to explain competitiveness, such as the industry structure view (Porter, 1980) which considers industrial factors as the bases of competitiveness, or the less known relational view (Dyer & Singh, 1998; Dyer & Nobeoka, 2000), which describes how partnerships can create relational rents which cannot be easily copied by competitors, we stay with the resource based view as we are looking for factors providing competitiveness from inside the companies. In the resource based theory the distinction between the terms "resources" and "capabilities" is fundamental. Grant (2002) defines resources as individual inputs of operations like capital equipment, human resources, intellectual capital, and so on. Teece et al. (1997), on the other hand, differentiate between factors of production and resources. According to them factors of production are undifferentiated inputs available in disaggregate form in different factor markets. Resources are also different assets of a company, but they have already some firm-specific content.

Both interpretations have a basic common feature, namely these resources do not create value on their own. In value creation processes these resources need to be coordinated and managed. Nelson & Winter (1982) emphasize that the permanent and matured patterns of coordination and management activities constitute routines. Definite sets of resources and the connected routines are defined as capabilities (Grant, 2002).

A third basic term of the resource based approach is competence. Authors of the CLM (Council of Logistics Management) research program called "World class logistics" (1995) interpret "competence" at a high level of abstraction. A company can possess different competences. Core competences are subsets of resources and capabilities that are fundamental to satisfying customer expectations (value dimensions) and consequently firm's performance (Hamel & Prahalad, 1990. Distinctive competences are those, where firms are particularly good relative to their competitors.

In our paper we also consider competence as a higher level building block of firm competitiveness, than resources and capabilities.

Thus firm competitiveness is in our understanding a function of two factors:

- To what extent a company can identify value dimensions that are important for their customers?
- To what extent is a firm able to successfully develop those sets of resources and capabilities (or competences) that make it able to create and deliver the identified important value dimensions?

In the following section of our paper we discuss the critical point of connection between these two sides.

3. Model

The model is an instrument for analyzing the internal structure of firm competitiveness. This model is summarized in Figure 1 below. On the basis of our model, the fit of customer expectations and core competences will determine the level of competitiveness. If customer expectations in any respect cannot be fulfilled by the supplier then the customer will look for substitution, or alternatively, makes attempt to teach the customer how to provide that value. In any way, the supplier is not competitive at the moment. Also, if the supplier has specific competence not required by its customers, then that competence does not help the company to stay in that particular business.

Today in B2B relations the features of delivered products are usually just the preconditions of future business. As customers have different and very detailed requirements and suppliers can provide specific packages, potential partners have to meet and know each other to identify the level of fit. Fairs, exhibitions, customer-supplier meetings, references can serve that purpose. Customers there get to know both the products provided and the providers themselves. Customer audits give further insight into the capabilities of suppliers which make sure the expected value would be provided for customers.

However, even if there is a fit at the moment, it can change over time as customers can increase their requirements or suppliers can build new capabilities and thus can provide more valuable packages.

The purpose of our interview based research is to discover closely related packages of customer value dimensions and core competences that are required to create them. According to our hypothesis automotive suppliers can develop and possess different type of such packages. Along the concrete sets of packages we create taxonomy of automotive suppliers.

In this paper we concentrate on the competence part of our model and will discuss customer value issues only as suppliers think about it.

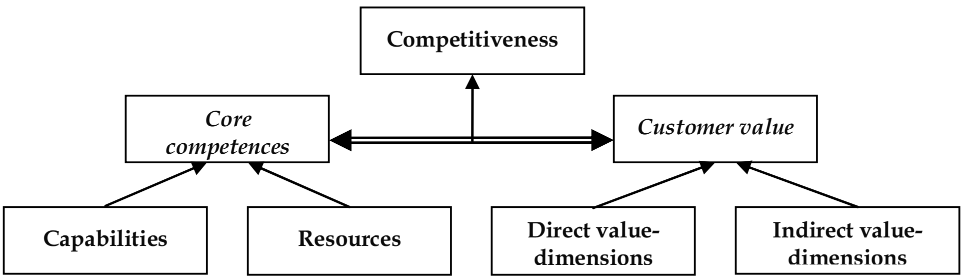

Figure 1. The buildup of firm competitiveness (Gelei, 2004)

4. Case selection

The research is based on multiple interviews, twenty one altogether. The automotive industry was selected because supply chain management is the most developed in the automotive industry. Due to its global nature, networking is one of the primary sources of competitiveness (Senter – Flynn, 1999). Actors of Hungarian automotive supply chains are interviewed to capture both expected customer value dimensions by customers and supplier core competences, including their understanding about the required value dimensions. Thus, the unit of analysis is the business unit in Hungary, even if we had to consider the global company background during the analysis.

Since our purpose is to find different service packages related to different customer requirements we strived for diversity (Stuart et al., 2002). Our first aspect was to go back to companies which took part in previous research (see Demeter et al, 2004). The reason for this is threefold. First, in that research we went through different levels in two supply chains which can assure the required diversity. Second, we can use additional information about the participating companies from the previous research. Third, we can see the progress these companies made in the last three years, which can help to identify important capabilities.

Seven of the 10 companies in our sample belong to this group. The other three companies came into the picture on various ways, but practically randomly: we found one of them on the internet, one of them on a conference and the third one is a supplier of another company in the sample. Four additional companies refused to take part in the research due to the lack of time, to ownership problem, to confidential purposes and to the lack of interest.

Depending on company size, the role in the supply chain and the availability of time the number of interviews varied from 1 to 4 by company. The length of interviews also varied between 45 minutes and 3 hours. The interviews were semi-structured and some additional documents were also collected from companies. The positions of interviewees are also diverse. We asked the managing director in case of one interview at a company.

Additionally, purchasing managers, sales managers, quality assurance people, a finance manager, and manufacturing engineers were asked for the interview. The most important characteristics (a fantasy name for the company based on the product they make, the number of employees, ownership, supply chain position, and interview information) are summarized in Table 1.

Cases	*Number of employees*	*Ownership*	*SC position*	*Number of interviews*	*Interviewees*
Jet	2800	Global	Tier 1	4	Quality, purchasing, sales and logistics managers
Vision	720	Global	Tier 1	1	CEO
Precision	393	Global	Tier 2	1	CEO
Nozzle	230	Local	Tier 2	2	Logistics and purchasing managers
Seat	860	Local	Tier 1 / 2	2	CEO, production manager
Cable	650	Local	Tier 1 / 2	4	Production, logistics, customer relations and finance managers
Pipe	150	Local, family	Tier 1	1	CEO
Bowden	50	Local, family	Tier 1	3	CEO, manufacturing engineer, quality manager
Sealing	30	Local, family	Tier 2	1	CEO
Plastic	15	Local, family	Tier 3	2	CEO, HR manager

Table 1. Case characteristics

First, we describe the cases shortly. Next the capabilities and resources are collected from the interviews. Finally, we try to find discriminating factors in order to make our taxonomy.

5. Case descriptions

Case "Jet" company is a subsidiary of a large Japanese multinational producing fuel supply systems (jets) in diesel cars. As a Japanese subsidiary it is very strong in production. 10% of the employees come from Japan and work with Hungarian engineers together to introduce new models in production, and to work intensively with suppliers in solving problems. Job rotation and cross-functional team working is commonplace. Product design takes place in Japan at the parent company. The head of each department is Japanese in order to keep consensus and understand cultural background of the parent. Consensus based decision making, however, slows down processes. Quality engineers are assigned to customers due to different requirements. Internal information systems are integrated; however, they are not integrated globally. They have a very thorough supplier and employee selection process, and they not refuse any company at the first sight. Training and education is very strong.

Case "Vision" company is a subsidiary of a German company producing mirrors and lamps (the vision system). The production facility is new, technology is transferred gradually. The subsidiary won two quality prizes. They brought up their supplier's employees in house; teaching the manufacturing culture of lean to them then outsourced that part of production. They have no warehouse, JIT delivery is usual. They have a logistics centre, however, near to one of their customers. They segment their suppliers clearly. Information technology is developed; they use globally integrated software, and issue kanban orders electronically. The parent company plans to replace product design to the subsidiary in the close future. The subsidiary makes improvements on the basis of customer audits.

Case "Precision" is a division of a subsidiary of a Canadian multinational company producing large precision parts and components. The division is very proactive, seeks continuously to make improvements. They plan to design a complete module in the close future, make improvements in automation and autonomation (jidoka) as well as in the logistics system. They rely heavily on multinational background by using the global engineering database, dividing tenders among the subsidiaries, and providing the capital as needed. The division builds strong relations with customers and suppliers, work closely together in new product introduction and problem solving. Group work is usual, fast feedback to employees is normal. Employee selection and initial training is very thorough.

Case "Nozzle" is a dynamically growing Hungarian company producing nozzles, hoses and connections, pipes, valves. They have strong product development skills compared to other suppliers. Now they target to develop a new pump in collaboration with a Hungarian university in order to have their own complete module. Since they did not find a good supplier of plastic moulding they built a factory, bought the necessary technology and do it themselves. Besides, they invest in logistics. They continuously feel the pressure of customers to increase capacity and deliver more and more products. Sometimes they are told to use a given supplier but usually they are free in supplier selection. They keep close contacts with customers and suppliers and consider trust as important. Case 10 is their supplier since the beginning. They have integrated information system and usually communicate electronically.

Case "Seat" used to produce complete seats but now they deliver only parts to it. In the last two years they completely renewed themselves: they have new, experienced management, downsized the company, and introduced centralized global purchasing, customer specific sales and lean management. All of these efforts were made in order to increase efficiency. They deliver JIT from their warehouse near to the customer. They do not plan to be more involved in product development.

The main business of Case "Cable" is machine building but they deliver cables and some engine parts to the automotive industry in order to get contacts there. They produce their own machinery and target to deliver machinery directly to OEM factories. They deliver cables in sequence and engine parts just in time. They cross-finance the preparation phase of automotive projects from their machine building business.

Case "Pipe" grows very dynamically. The key to their automotive business is a new manufacturing technology developed but not patented yet. They produce pipes to cooling systems. The main driver is the CEO who got into the automotive business due to his strong problem solving skills. The palette of businesses is very diverse. They use developed IT, take part in electronic auctions, operate CAD system. They just built a new factory. The CEO and his team are very active in seeking new customers. They are customer, quality and process oriented. The CEO is open to speak with the last employee if needed; he himself brings up the future production manager.

Case “Bowden” is a small family owned business delivering Bowden to OEM. The company places high emphasis on quality management. They won the best supplier prize more than ones. They have CAD system and they are able to suggest technical changes in the product. They make changes on machines and able to construct their own machines. They are ahead of relocation because of the lack of space. The company entirely depends on the owner and his father. The owner is the chair of the association of part supplier companies in Hungary.
Case “Sealing” produces rubber products, eg. sealings to Case ”Jet”. They make large efforts to raise money from grants for their investments. They enlarged their factory, bought new machines in the last two years and plan further significant investments. They actively try to find other businesses in order to reduce risk. They are able to receive drawings in autoCAD and contribute unofficially to product development through information exchange. The owner attends conferences and himself delivers products to the customer. The whole company relies on him.
Case “Plastic” is a very small family owned company of long personal relationship with Case ”Nozzle” producing small plastic parts. They have some new and some old machines to work with in a new facility. They are not able to get new customers and orders although they have the required quality certification. They have some problems with documentation, the customer helps them. They have a small program to manage their business and able to communicate through e-mails. They were unsuccessful in winning grants for investments.

6. Case analysis

During the case analysis we assumed that companies more or less understand the customer value so they develop capabilities which can help them to fulfil customer requirements. Actually, this assumption is a basic one in quality certificates. Of course, sometimes there is a time lag between recognizing a value dimension and developing capabilities to satisfy the customer. But in this case companies usually start to work on this weakness.
First, we collected all the resources and capabilities that we found in the interviews. Next, resources and capabilities were grouped. In our terminology these groups can be considered as competences. Since we are looking for values provided for the customers, Porter’s (1985) value chain concept seemed to be appropriate to put logic behind the collected competences. The most important competences through the value chain, grouped as primary and supporting activities, the connected capabilities and resources are shown in Table 2.
After collecting capabilities we thoroughly went through the cases and identified the level and kind of competences that the companies have. Comparing the cases we found the following discriminating and common competences and resources (Table 3).

6.1 Discriminating factors

Product design competence. Multinational companies use different strategies. Case “Jet” makes product development in Japan. Case “Vision” strives to replace product design to the subsidiary where the product is manufactured. This latter might be explained by the relatively high customization requirement of the products. In case of “Precision” product development initiatives come from inside the subsidiary but supported by globally developed engineering database. Case “Nozzle” is the only Hungarian company which targeted to develop its own product with the clear objective to become tier 1 supplier. Important to see that while Case “Jet” and “Vision” has its own products (although

Primary activities (competences)			
Product design	*Production and its development*	*Logistics (in and out)*	*Marketing and sales*
Capabilities			
Engineering knowledge (understand and solve construction problems) Cooperation with partners in design Manage ramp up die production in place	Lean production (use cells, robots) Manage technology Engineering knowledge (read drawing, discover problems) Preventive maintenance High quality products development Manufacturing and technology development	Warehouse logistics, inventory tracing Keep contact with suppliers and customers (call down, delivery) - Kanban, JIT, JIS, delivery	Customer specific customer relations Diplomacy in negotiations Informal relations with customer representatives (cards, flowers)
Main resources			
Internet based databases for engineering solutions	Machines Measuring devices Experts Facilities (clean, air conditioned)	Software, Barcode equipments	- Databases
Supporting activities (competences)			
Strategic management	*HRM*	*Purchasing*	*Information management and communication*
Capabilities			
Get new business Several legs – stability Shape company culture consciously Proactive view Outsourcing decisions Global organization solutions Kaizen Fit to ever changing requirements - Cross-functional teams	Motivating employees Employee selection Feedback to employees Training and education	Supplier relation management Centralized purchasing Global purchasing Supplier selection and evaluation system Supplier audit Supplier segmentation	Maintain information flow Information exchange with partners (EDI) Communication Quality assurance system (documentation) Write applications for grants Prepare presentations for customers
Main resources			
Leaders Employees Devices to detect changes (Attend conferences)	employees	IT hardware & software ERP EDI AutoCAD fax, phone	IT hardware & software, ERP EDI AutoCAD Fax, phone

Table 2. Competences, capabilities and resources collected from the cases

developed elsewhere), it is only an objective yet at Case "Precision" and "Nozzle". These latter companies consider product development as a tool to reach higher place in hierarchy.

Case “Seat” is a counter example for product development competence. It developed neither its product nor the process in its existing projects. Thus in new projects it found itself in tier 2 position instead of tier 1. It produces now only the parts of the module that it produced before, since the customer decided to make the module in house.

Case	*Product/ technology innovation*	*Quality certificate*	*Proactive/ reactive view*	*Several legs strategy (beside automotive*
Jet	Global product, local technology adaptation	ISO-TS 16949	Globally proactive	No
Vision	Global product, local technology adaptation	ISO-TS 16949	Globally proactive	Yes (electronics)
Precision	Global/local product/technology development	ISO-TS 16949	Globally and locally proactive	Yes (electronics)
Nozzle	Local product/technology development	ISO-TS 16949	Proactive	Yes (parts in cosmetic equipments)
Cable	Technology development, (new products not in automotive)	ISO-TS 16949	Proactive	Yes (machines for agriculture and automotive)
Seat	Technology adaptation	ISO-TS 16949	More proactive than before	No
Pipe	New technology invented	ISO- 9001:2000	Proactive	Yes (very diverse)
Bowden	Technology development	ISO-TS 16949	Less proactive	No
Sealing	Technology adaptation	ISO- 9001:2000	Less proactive	Not yet
Plastic	Nothing	ISO- 9001:2000	Reactive	Yes (construction)

Table 3. Some important discriminating and common factors

Production (technology) development competence. All but one company are able to make changes in their technology to adapt it to new products or to changing conditions. Die production in place (Case ”Nozzle”, ”Seat”, ”Bowden”, ”Sealing”) can fasten this adaptation process. Case “Plastic” use the technology as it is.

Strategic management competence

Proactive strategic view. We found four companies which had a very clear view on where they want to go. Due to the strong vision they have, they do not wait for the customer, but do what they think they need in order to step forward. Case ”Precision”, and ”Nozzle”, as discussed before, place high emphasis on own product development. Case “Cable” is special since they consider automotive delivery as a tool to become a direct supplier of automotive machinery. They realized, first they have to make potential customers know who they are. Case “Pipe” builds on the extremely strong problem solving skills of the

owner. They have just started in the automotive industry due to a new technology they developed. This company realized that the only chance to become an automotive supplier if they have a much better offer (price) than anyone else. So they decided to develop a new technology. This technology can reduce the energy cost of production from 100% to 8% which results in huge savings. The common in all these cases that they are not satisfied with their current position. Case "Precision" and "Nozzle" want to become tier 1 instead of tier 2, case "Cable" want to get closer to potential customers of their core product, and case "Pipe" wants to become a stable automotive supplier.
Lack of capital. There are strategies among Hungarian companies to handle this problem. Some of them cross finance the preparation stage of automotive projects from other businesses. Those who have several legs can use this policy. Several legs strategy reduces the risks and help to step dynamically. Other companies involve external funds through grants or by partnerships, but it is important to see that state support grants are very slow and can help only those who can pre-finance their projects. The lack of capital prevents companies from product design.

6.2 Common factors

There are some competences which can be detected at each company (they are the qualifying criteria in the automotive industry). Of course there are differences in the level of the competence.

- *Manufacturing competence:* all the involved companies have relatively high manufacturing competence. All of them have ISO standards which regulate physical, administrative, information and problems solving processes. Although there are differences in the level of the certificate, but all of the companies reaches the ISO 9001:2000 level.
- *Information management competence*: even the smallest company has internal databases and electronic connection (but not EDI) to the customer.
- *Marketing and sales competence*: Customer relations are managed carefully at each company. In larger companies customer specific organizations help closer contact, while at smaller companies usually the owners themselves are responsible for these contacts.

Some important factors are summarized in Table 3.

7. Develop taxonomy

The developed taxonomy and some of our preliminary findings related to it are summarised in Table 4. Important to emphasize that the types build on each other which means that higher levels include all the capabilities available at lower levels.

7.1 Capacity based suppliers

These suppliers provide resources for production. Build the factory, buy the necessary equipment and employ people who can execute the required tasks. They do what the customer wants but do not make proactive steps. Even these companies have to have quality certificate since ISO-TS 16949 does not let suppliers into the system without this standard. Capacity based suppliers keep close contact with their customers in order to make them satisfied. They have integrated database but have very limited communication abilities electronically.

Type of suppliers	**Capacity based**	**Adaptation based**	**Innovation based**	**System and innovation based**
Cases	″Plastic″	“Seat”, “Cable”, “Pipe”, “Bowden”, “Sealing”	″Nozzle″	″Jet”, “Vision”, “Precision”
Product – service offering	Capacity	Product and technology knowledge	Innovation	Supplier network and innovation
Core competences	Production	Technology and minor product adaptation	Strategic innovation competence	System competence: coordination, logistics and innovation competences
Some important capabilities	High quality product, integrated database, customer relations	Die production in place, some proactive view	Own product design	Global organization, supplier segmentation, logistics management

Table 4. Supplier taxonomy

7.2 Adaptation based suppliers

Some level of proactive thinking can be detected in these companies. For example, although they are not involved in product design, they get the engineering drawings with autoCAD and they make suggestions for minor changes in the product before or during serial production. These suggestions are informal but sometimes are listened to. Moreover, they are able to change the available technology to make it fit better to the requirements. Not all of them, but the majority is able to produce its own dies which make these companies more flexible and cost efficient. Some of them offer to increase value added in the product.

7.3 Innovation based suppliers

The main competence of these companies, that they have their own product design. This requires a very clear strategic thinking, strong engineering knowledge and capital to invest in new product development. Innovation based suppliers need not only understand the current customer requirements but have to know in which direction they have to develop the product. The only one case we found shows that finding appropriate partners can help to reduce the risks and costs of investment.

7.4 System and innovation based suppliers

These companies are multinational and they utilize this global feature. They use their resources globally; for example, they develop the products in a strong engineering centre or in close collaboration with the customer on the required geographical area. They share experts who travel to the subsidiary if needed. They share engineering databases to adapt products and technology faster. They have very strong financial background, which make them flexible in reacting to any customer needs. They are module suppliers. They have strong logistics capabilities to organize supplier deliveries. They segment their suppliers and apply global purchasing.

8. Discussion

Companies can change place in this taxonomy. The best signal that they want to do that is the level of proactive thinking. Also, the lack of proactive thinking can lead to step back. Company 6, for example, lost its position as an innovation based supplier since it did not make efforts to make improvements is seat design. The build-up and characteristics of supplier types are summarized in Figure 2.

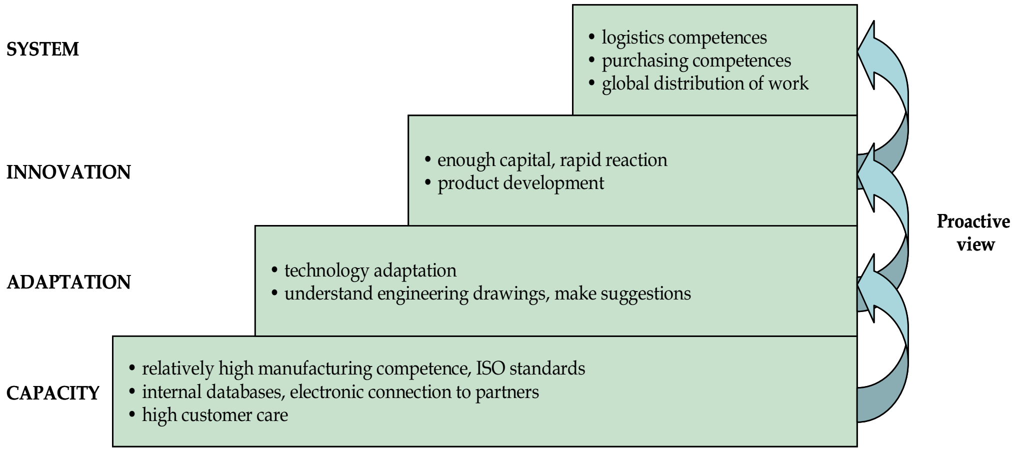

Figure 2. The most important competences of supplier types

Our taxonomy has close relations to other typologies. For example, the classical pyramid structure (eg. Senter, R. & Flynn, 1999) which categorize companies as tier 1/2/3 suppliers have clear linkages to our categorization. Tier 1 suppliers usually belong to the group of system and innovation based companies, they are the so called integrators. Tier 2 companies belong to either adaptation or innovation based groups. Tier 3 and down usually belong to adaptation or capacity based groups. However, that categorization is not based on capabilities that companies have, but on their position in the supply chain. If we look at our cases, Case 3, 7 and 8 are not on the place expected. A capability based approach is provided by Kamath & Liker (1994) who group companies on the basis of their involvement in product development and categorize companies as partner, mature, child or contractual companies. That typology, however, concentrate on innovation based capabilities only. The closest categorization to ours is that of Haffmans & Weele (2003). They use three groups: those who a) carry out processes, b) supply their own product, or c) compose modules and systems. Compared to ours, group a) is equivalent to the capacity or adaptation groups, group b) fit to our innovation based groups, but also involved in the system and innovation group, and group c) partly matches our system and innovation group but those companies have innovation capabilities, as well. We believe that based on the categorization of Kamath

& Liker we have to make difference between those who make contributions to product design (child) and those who just simply do what is requested (contractual). Furthermore, those who belong to group c) have the innovation capabilities, as well.

9. Conclusion

Our paper discusses how local supplier companies in global supply chains can be competitive. We applied a general model of competitiveness for Hungarian automotive supplier companies using information of 21 interviews. On the basis of understood customer values, plus supplier resources and capabilities taxonomy was developed, which help companies to decide in which direction they should improve their capabilities. We identified four supplier types: a) capacity based, b) adaptation based, c) innovation based and d) system and innovation based companies.

Our taxonomy is a useful instrument both from theoretical and practical point of view. Building on and synthesising the findings of two important management research areas – the customer value approach and the research based strategic management - will give a clearer understanding of and a deeper insight into firm competitiveness. The supplier types suggested will also help supplier companies in the automotive industry to analyse their strategic position, development possibilities and formulate viable strategies.

Although companies in our research operate in Hungary, they are parts of global supply chains often exporting their products. Thus, based on literature and our experiences, the generated taxonomy is usable all around the world in the automotive industry. However, the automotive industry has a specific supplier structure, and much more global than other industries. Thus the taxonomy itself is applicable only in this industry. On the other hand, the model of competitiveness and the process applied to collect capabilities is very general and widely applicable anywhere.

In this paper we analyzed only the competence part of our model assuming that suppliers are familiar with the requirements (the customer value) they face. Detailed analysis will be required in the future to consider the customer value part more deeply, as that part must be the starting point for suppliers. Since our results are based on some interviews we consider this taxonomy as preliminary. We plan to develop a survey to collect information more systematically. Also, based on the model and process we will analyze other supply chains (such as FMCG) to find the competence structures there.

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27

Design of Multi-Behavior Agents for Supply Chain Planning: An Application to the Lumber Industry

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1. Introduction

New economic challenges and recent trends regarding globalization have forced companies of many industries, including the Canadian lumber industry, to question aspects of their organizations. Many of them have looked to reengineer their organizational processes and business practices and adopt supply chain management best practices. An aspect studied by many researchers recently is supply chain sales and operations planning, which deals with the management of client orders through the supply chain. Each partner involved must decide quantities and production dates, and allocate resources for each product needed, with respect to production capacities and transportation delays. Coordination between production partners is essential in such a context in order to deliver products on time to final clients. As perturbations occur all the time in such complex system, production centers have to react quickly to correct deviances and create new plans, while coordinating changes with partners.

At the structural level, centralized approaches handle supply chain planning and coordination with difficulty, mainly because of the complexity of such problems and the challenges of sharing private information between partners. Decentralized approaches are now being considered to overcome these problems, giving different partners the responsibility to locally plan their production, using coordination schemes to insure coherent supply chain behavior. Agent-based technology provides a natural approach to model supply chain networks and describe specialized planning agents. On the other hand, decentralized approaches are generally sub-optimal. Heuristics are used by agents to coordinate and optimize their production plan in order to reach feasible global solutions. Because a local change in a plan can impact other partners, a coordination mechanism must be used to insure that every partner is informed of the change and can make their own changes if necessary.

Most of the time, system designers or production planners select a planning heuristic at design time, choosing what they believe to be the best decision for their specific application. The main problem is that the heuristic may not be adapted to further perturbations or environmental conditions the planning agents will face in a production context. Usually, these local algorithms used by agents can be parameterized on several levels (such as objectives, penalties, etc.), creating a variety of planning behaviors for an agent. We call a local planning behavior any planning strategy used by an agent to construct a production plan. A global planning behavior, or team behavior, is the combinational result of all local behaviors demonstrated in the supply chain. The task to set behavior parameters for every agent composing the supply chain is complex because all these setting are interdependent. In a dynamic environment it is extremely difficult, and sometimes even impossible, to correctly specify these parameters a priori, at the time of their design and prior to their use (Weiss, 2003).

Our main argument is that it is preferable not to choose a specific behavior for each agent at design time, but to develop agents possessing different planning behaviors. We term them *multi-behavior agents.* Confronted with a perturbation, an agent can dynamically change the planning and coordination mechanisms and, ultimately, increase supply chain performance through improved coordination. The idea is not to handle every single perturbation (there will be always be a need for human interventions), but to automate certain perturbations with effective known responses.

This chapter presents a framework to design such agents, to help identify perturbations, propose planning behaviors, and how to use experiment and simulation to adopt the best behavior for specific situations. Section 2 provides a literature review on agent-based supply chain planning, coordination in supply chain, adaptive agent-based planning and learning agents. Section 3 presents the proposed framework to design multi-behavior agents, explaining how different planning behaviors can be identified, compared and introduced in an agent-based planning system. In Section 4, we give results from an application of the framework to the lumber supply chain. Finally, section 5 presents a conclusion and provides an overview of intended future work.

The North American lumber industry represents a perfect context for this proposal. In fact, this industry is highly distributed, with many production units geographically dispersed, interacting in all activity levels, using a variety of specific planning processes. What makes this industry interesting for research is the large amount of stochastic perturbations in many aspects of the supply chain, mainly due to the highly heterogeneous aspect of the resource, uncertain process output, production of co-products and by-products, price variation in the spot market demand, resulting in a variation in commodity markets all inducing a very complex planning activity.

2. Literature review

In order to understand the research context of this chapter, this literature review covers the literature from organizational approaches to more functional approaches. Distributed supply chain planning approaches are first reviewed and agent-based planning is presented as a particularly interesting paradigm to manage supply chain planning. Next, in order to create a coherent environment, coordination mechanisms used in these approaches are presented, including negotiation between partners. Because agent-based planning systems can be made of a variety of agent types, a closer look at functional agent mechanisms is then made by investigating agile planning agent architectures. Finally, a specific agent characteristic is investigated, which is the ability to learn.

2.1 Distributed supply chain planning

Traditionally, centralized planning systems have been used for production planning in a single company. Offering a complete view of the production activities, they usually use optimization algorithms to find the best production planning solutions. In a distributed context like supply chains, where different partners work together to deliver goods to final customers, planning problems become rapidly too complex to solve centrally. Centralized planning systems tend to be rigid under dynamic system environments and are less likely to succeed than distributed approaches (Alvarez, 2007). Also, supply chain partners are usually reluctant to share private information that can be crucial to their competitiveness. In centralized systems, this typically leads to incomplete information and sometimes infeasible plans.

Different paradigms have been studied to operate distributed systems, such as fractal factory, bionic manufacturing, holonic manufacturing and the NetMan paradigm (see Frayret et al., 2004 for a review) and many resolving approaches have been applied, including integer programming, priority dispatching rules, heuristics (Alvarez, 2007) and constraint programming. Another trend in supply chain operational planning has resulted in the development of agent-based planning systems. Agent-based systems focus on implementing individual and social behaviors in a distributed context, using notions like autonomy, reactivity and goal-directed reasoning (Bussmann et al., 2004). They are computer systems made from a collection of agents, defined as intelligent software with specific roles and goals, interacting with each other to make the best decision according to the situation and its goals, in order to carry out their part of the planning task (Marik et al., 2001).

Several articles present reviews of research projects related to planning, scheduling and control, using agents (Shen et al., 2006; Caridi & Cavalieri, 2004, Frayret et al., 2005; Moyaux et al., 2006). Among these projects, Montreuil (Montreuil et al., 2000) presented a NetMan application, which is an operation system for networked manufacturing organizations that aims to provide a collaborative approach to operations planning. The ExPlanTech multi-agent platform (Pechoucek et al., 2005) gives decision-making support and simulation possibilities to distributed production planning. Relying on communication agents, project planning agents, project management agents and production agents, the platform uses negotiation, job delegation and task decomposition instead of classic planning and scheduling mechanisms to solve the coordination problems. In order to reduce communication traffic, social knowledge is precompiled and maintained, which represents information about other agents. The FORAC experimental agent-based planning platform (Frayret et al., 2005) presents an architecture combining agent-based technology and operation research-based tools. The platform is designed to simulate supply chain decisions and plan supply chain operations. Each agent can be designed with specific planning algorithms and is able to start a planning process at any time, following a change in its environment. More details will be given of this platform in section 3.

2.2 Coordination in supply chains

As discussed previously, distributed planning provides clear advantages over centralized planning for supply chains, but represents a major challenge for coordinating the independent planning centers in order to build coherent and efficient production plans. In fact, without coordination, a group of agents can quickly degenerate into a chaotic collection of individuals (Shen et al., 2006). The coordination between planning centers is essential because decisions concerning production planning are interdependent and have an impact on partners (Moyaux et al., 2006). These interdependencies need to be managed, which requires building coordination mechanisms to keep a certain degree of coherence between the different decision centers (Frayret et al., 2004). These coordination mechanisms are in fact sets of rules that partners use to choose their own planning activities. Different categories of coordination mechanisms have been proposed for distributed systems, but can be summarized in five basic categories: third party coordination, coordination by mutual adjustment, coordination by standardization, mediated coordination and coordination by reactive behaviors (Shen et al., 2001). A new classification has been proposed (Frayret et al., 2004), which tries to overcome certain limits of previous classifications, including a distinction made between coordination before and during activities.

Negotiation is a common supply chain coordination approach, as a part of the mutual adjustment category. Jiao (Jiao et al., 2006) identifies negotiation as crucial to successfully coordinate different supply chain entities. Various negotiation strategies can be deployed, including contract based negotiation, market based negotiation, game theory based negotiation, plan based negotiation and AI based negotiation (Shen et al., 2001). Dudek and Stadtler (Dudek & Stadtler, 2005) proposed a negotiation-based scheme between two supply chain partners, using a convergence mechanism based on exchange of local associated costs. Different agent-based manufacturing systems using negotiation have been proposed (see Shen et al., 2001; Shen et al., 2006). Among them, Jiao (Jiao et al., 2006) presented an agent-based framework that enables multi-contract negotiation and coordination of multiple negotiation processes in a supply chain. Monteiro (Monteiro et al., 2007) proposes a new approach to coordinate planning decisions in a multi-site network system, using a planning agent and negotiation agents. The negotiator agent is responsible to limit the negotiation process and facilitate cooperation between production centers. Chen (Chen et al., 1999) proposed a negotiation-based multi-agent system for supply chain management, describing a number of negotiation protocols for functional agent cooperation.

While most of these agent-based supply chain planning approaches use a specific coordination and optimization mechanism to face a perturbation and develop new production plans, they can be insufficient in dynamic environments. Many complex and unpredictable situations require planning agents to adapt their behavior to their environment and change the coordination and optimization mechanism used. This leads to the need to design and implement highly adaptive multi-behavior agents.

2.3 Adaptive agent-based planning

When the planning environment shows a high level of variability and perturbation, common to a supply chain context, planning agents are asked to create or review production plans continually. In some situations, it could be advantageous for agents to adapt their planning behavior and use different coordination and optimization mechanisms. Such adaptive planning requires developing new kind of agents. Different adaptive agent models have been proposed in the literature, some of them specifically designed to improve supply chain performance

One of the best known is the InteRRaP architecture (Muller, 1996). This layer-based agent model provides an interesting approach to react and deliberate when confronted with perturbations, using different capability levels. The agent can build action plans, depending if an event requires a reactive response, local planning or collaboration for planning. The Agent Building Shell (ABS) (Fox et al., 2000) is a collection of reusable software components and interfaces needed for any agent involved in a supply chain management system. The ABS is geared to handle perturbations caused by stochastic events in a supply chain. An interesting simulation is presented using ABS agents to analyze the impact of coordination in supply chains when facing unexpected events. Another adaptive agent model is the tri-base acquaintance model (3bA) (Marik et al., 2001). It provides the possibility of dealing with perturbations in a global perspective instead of resolving problems from a local perspective. This is accomplished by using information about other agents without the need of a central facilitator. Theses authors present some applications to supply chains and they define the social knowledge needed to increase the efficiency of agents. In the MetaMorph adaptive agent-based architecture (Maturana et al., 1999), mediator agents are used to facilitate the coordination of heterogeneous agents. These mediators assume the roles of system coordinators and encapsulate various mediation behaviors (or strategies) to break decision deadlocks. Jeng (Jeng et al., 2006) proposed an agent-based framework (Commitment based Sense-and-Respond framework – CSR) which is an adaptive environment for continuous monitoring of business performance and reacting to perturbations, using multiple decision agents. An application to the microelectronic supply chain is presented.

These agent architectures all offer the possibility of adapting their behavior when a certain situation occurs. Some of them know beforehand which behavior must be used for each situation, while other agents successively try different alternatives. More advanced agents compile the performance of past experiences and learn from it: these are the learning agents. The multi-behavior agent model is inspired by these architectures, possessing alternative behaviors for different situations and using learning abilities to link successful behaviors to situations.

2.4 Learning in supply chain planning

Multi-behavior agents in supply chain show many promising features. However, linking behaviors with environmental conditions can be a hard task, even for experienced system designers. The main reason is that most changes and perturbations in manufacturing environments are not predictable in advance (Shen et al., 2006). Environmental conditions can change so that what was preferable at the design time is not anymore. This raises the need for agents that can not only adapt but also learn (Weiss & Sen, 1996). Agents then have the possibility of recognizing situations and applying the best behavior instead of trying each of them one at the time. Alonso (Alonso et al., 2001) argues that learning is the most crucial characteristic of intelligent agent systems.

Many researchers have been investigating learning agents, from defining fundamental issues of intelligent learning agents (Schleiffer, 2005) to describing major learning techniques for multi-agents systems (Alonso et al., 2001; Weiss & Sen, 1996). Shen (Shen et al., 2000) present a research review related to the enhancement of agent-based manufacturing systems through learning, including the use of learning in a more general manufacturing context. Among them, mediator agents in the agent-based architecture MetaMorph (Maturana et al., 1999) use two learning mechanisms, *learning from history* and *learning from future*, in order to enhance the manufacturing system's performance and responsiveness. Crawford (Crawford & Veloso, 2007) recently studied how agents can learn to negotiate strategically to reach better performance. To create adaptive and learning agents, Fox (Fox et al., 2000) uses the Markov decision processes in conversation protocols. Each action included in the protocol has a probability to cause a transition to a determined state. From obtained results, the agent updates probabilities, which change agent behavior over time.

In a case where multiple agents must cooperate and coordinate their actions, they can learn together how to maximize their global performance; it is called cooperative multi-agent learning. Panait (Panait & Luke, 2005) presents a complete review on this topic, including team learning and concurrent learning. Basically, team learning involves a single agent learning for an entire group, specifying the set of behaviors for every member, while concurrent learning describes the use of multiple agents, where each one is responsible for a certain learning space.

3. Behavior design framework

This section presents a framework to design multi-behavior agents, using a multi-behavior agent conceptual model. The basic steps are described to give a design guideline, including the identification of the environment characteristics (perturbations) which require the adoption of a new behavior, the description of different behaviors available to react to perturbations, experiments to identify the best behaviors for different situations, simulations for continuous adaptation and finally, implementation and continuous learning.

3.1 Identification of perturbations

In a highly dependent network of entities, when activities are tightly planned, perturbations can have important impacts throughout the supply chain. For example, a major mechanical breakdown in a strategic third-tier supplier can reduce supply availability for several days, which can trigger a cascade of perturbations within the supply chain, translating into a delay for the final client. Another example is a quick change in demand pattern. When such changes happen, every local production plan and demand plan exchanged between partners must be updated. If it is not done in a very short period of time, inventories will pile-up, money will be wasted and the client will be unsatisfied. The first step in the methodology is to identify a maximum number of perturbations that show an impact on production plans. Table 1 presents examples of perturbation in the lumber industry and their related impact, obtained during interviews with decision takers. Inspired by Davis (Davis, 1993), perturbations have been classified into three categories: demand, execution and supply. Each of these renders current production plan inadequate. In order to correct this deviation and retrieve a feasible plan, agents must take action to change production plans.

For each perturbation, it is necessary to identify environmental conditions that would change the intensity of the impact on the supply chain. An environmental condition is any identifiable state that may change the kind of response needed. For example, a minor mechanical breakdown will not have the same impact depending on the level of use. This information represents the planning environment that agents must analyze to make decisions concerning their actions.

Perturbations	Impacts
Demand Variation	
Changes in product price	Changes in demand plan
New purchase order	Changes in demand plan
Execution Variation	
Out of stock	Execution delay
Strike	Execution delay
Resignation	Execution delay
absenteeism	Execution delay
Power outage	Execution stopped
Minor mechanical breakdowns (few hours)	Execution stopped
Major mechanical breakdowns (few days)	Execution stopped
Corrective maintenance	Execution delay
Stocks lost, misplaced	Execution delay
Resrouce different as expected	Changes in supply
Machining time longer	Execution delay
Wrong product produced	Changes in supply
Out of tranport (lack of trucks, wagons)	Delevery delay
Supply Variation	
Politic disorders (environnementalists, etc.)	Execution stopped
Bad weather	Execution delayed or stopped
Resource production different from forecast	Changes in supply
Transportation delay	Execution delayed or stopped

Table 1. Examples of perturbations

3.2 Identification of planning behaviors

The second step is to identify possible planning behaviors available to agents to respond to the perturbations previously identified. Different behaviors can be specific for specialized agents, while others can be more generic, all leading to far different performances depending on perturbations and environmental conditions. We distinguish two kinds of planning behaviors, which are optimization behaviors and a coordination behavior. The former characterizes different planning optimization algorithms and heuristics available for the planning problems. Various optimization algorithms have been applied to production planning and are available in the literature, such as JIT, forward planning and FIFO (first in first out). Also, different research heuristics can be used, like branch-and-bound, tabu search and genetic algorithms. The latter refers to mechanisms used to coordinate plans between partners. It can concern changing the order of planning actions between partners or the type of rule used to exchange information.
This step identifies planning behaviors, without associating them to any specific perturbations. All different behaviors must be identified, even those which at first sight seems less effective.

3.3 Team learning experiments

The complexity of supply chains makes it very difficult to identify which agent behavior is favorable for different environmental situations. Using learning abilities, agent designers do not need to make initial decisions on linking behaviors to situations. Agents experiment with different environment situations, adopt different planning behaviors and observe the results. The third step is the team learning experiments, where agents experiment with different planning behaviors together and gather information on obtained performances. The objective of this learning process is to test all combinations of planning behaviors for every agent, in all environmental conditions. Each of these combinations creates a different team behavior. Performances from all team behaviors are gathered for each environmental condition toward different performance indicators (ex. maximizing profit, minimizing inventory, minimizing lateness, etc.). Results from these experiments are put in a knowledge matrix indicating to the agent the best planning behavior available for specific environmental conditions.

Such experiments must be realized following a clear strategy of experimentation. This includes the number of replications, the order of experimental trials, randomization restriction and the type of statistical analysis to check the validity of the results. The reader is invited to refer to Montgomery (Montgomery, 2005) for further details.

3.4 Test simulation

The next step is to use knowledge matrix previously built from team experiments to run simulations over a rolling horizon. Instead of using a fixed planning horizon with the same behavior corresponding to a specific perturbation, multiple perturbations can be observed and behavior changes can be applied. This more realistic approach enables the possibility of comparing the performances of an agent switching behaviors when it is necessary, to an agent keeping the same behavior. Again, a strategy of experimentation must be designed and results must be verified with proper statistical analysis.

The execution of these simulation runs verifies assumptions made previously by the team learning experiments. Agents can update their knowledge and become more accurate when responding to perturbations. Work is currently in progress to gather data from these simulations and verify the performance increase.

3.5 Implementation and continuous learning

The last step of the framework is the implementation of behaviors in a production context and the use of multi-behavior agents for on-line planning of production activities. In order to continuously check planning performance of behaviors for specific environmental conditions, continuous learning represents an interesting approach. Periodically team learning experiments can be executed and agents can modify designed relations according to new results. Multi-behavior agents geared with learning abilities would be able to update their preferences.

4. Results

An application has been developed to test the proposed framework for the lumber industry. In this section, the application context is first described, including the agent-based planning platform used to implement the agents, the multi-behavior agent model followed to coordinate the different behaviors and the industrial base case used for experiments and simulation. Then, details of the framework application are given for each step, as well as the obtained results.

4.1 Application context

4.1.1 Agent-based planning platform

With the purpose of developing a new operation management approach for the lumber supply chain, the FORAC Research Consortium has developed an experimental Internet-based planning platform built on an agent-based architecture for advanced planning and scheduling (Frayret et al., 2005). This platform allows the different production centers to independently plan and correct deviance in line with their own needs, while maintaining feasibility and coordination. By distributing planning decisions among specialized planning agents using adapted optimization tools, the platform increases supply chain reactivity and performance. More than a planning tool, this platform can also be used to simulate different supply chain configurations and coordination mechanisms.

The agent-based architecture presented is based on the functional division of planning domains, inspired by the SCOR model proposed by the Supply Chain Council (Stephens, 2000). Figure 2 presents an example of a planning unit, including external exchanges with suppliers and customers. Planning units divide activities among specialized production planning agents: a sawing agent, a drying agent and a finishing agent, since each of these planning problems are quite different in terms of the way the process and the set-up are conducted. Each of these agents is responsible for supporting the planning of its production center in terms of production output each day. Other agents are also part of the architecture, such as the deliver agent, source agent and warehouse agent. The validation of these developments was carried out with the collaboration of a Canadian lumber company.

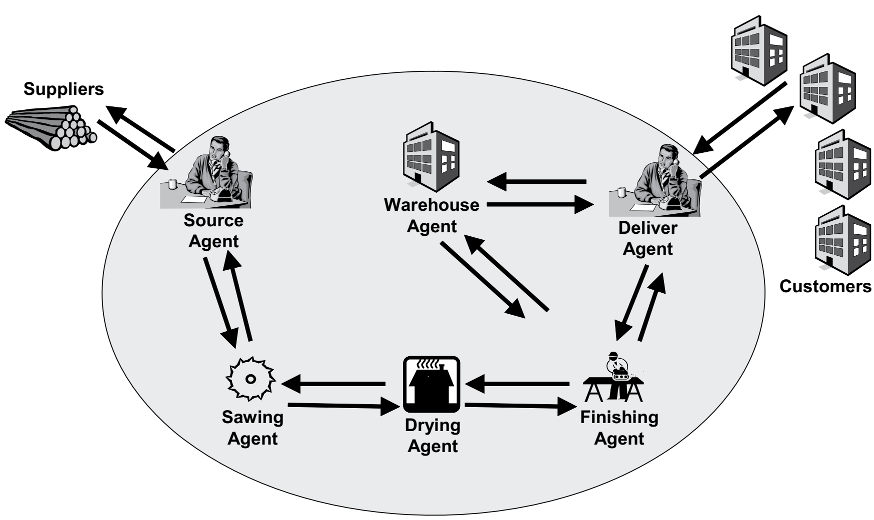

Figure 2. Example of a planning unit from the FORAC experimental platform

Implementation of multi-behavior agents in the platform is simple since every agent is loosely coupled with others. Each agent can be removed, replaced or modified with a minimum of manipulations. It becomes easy to modify agent's behaviors on the fly and observe performance in simulations.

4.1.2 Multi-behavior agent model

The framework presented in the previous section is a guideline to design multi-behavior agents based on the multi-behavior agent model. These multi-behavior agents can replace or enhance any existing planning agents in the experimental platform. In order to specify how works a multi-behavior agent, a descriptive model has been proposed (Forget et al., 2006) and a brief description is presented here.

The multi-behavior agent model presents three basic behavior categories, inspired by the coordination mechanisms found in the literature (Shen et al., 2001; Frayret et al., 2004; Moyaux et al., 2006). They are identified as Reaction, Anticipation and Negotiation. Each of these categories includes different planning behavior variations, from which the agent has to choose. While mono-behavior agents construct plans using the same planning strategy continuously, multi-behavior agents can adopt different planning behaviors, depending on the environment. Multiple behaviors can be designed and added in order to create adapted response to the environment. Figure 3 presents the multi-behavior agent model.

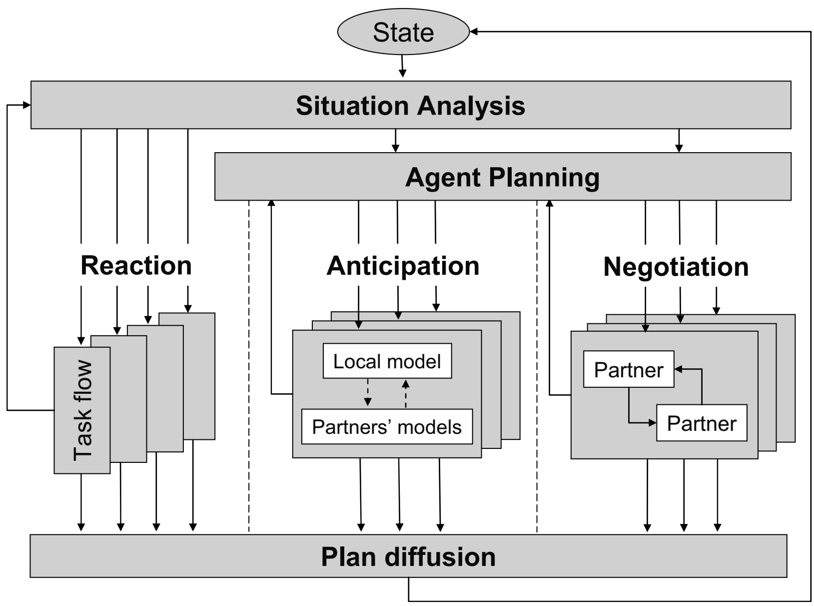

Figure 3. Multi-behavior agent model

Because the agent is not controlled by a central supply chain planning system, it is free to decide which action it will perform, using its own preferences. From a new state in the environment, the agent first starts the *Situation Analysis* phase. An analysis of the agent environment is performed in order to determine if a reactive behavior or a deliberative behavior must be selected. Reactive behaviors use no new information during processing. The agent uses its own knowledge and local goals to respond to a perturbation. A large variety of task flows or algorithms can be available, some of them taking a considerable amount of time but leading to optimal solutions, others finding acceptable (but not optimal) solutions in a very short period of time.

If more deliberative behaviors must be adopted the *Agent Planning* phase is started. The agent deliberates to decide which planning behavior it should adopt, using different selection criteria, such as available time, chance of success of a particular task flow, source of the perturbation and local goals. Researchers have presented several approaches to select the best task flow in a shop floor context, using case-based reasoning and heuristic search techniques (Aytug et al., 2005). This model uses a rule-based reasoning approach with learning abilities.

Two kinds of deliberative behaviors have been identified, Anticipation and Negotiation behaviors. Anticipation behaviors consist in using partners' models in addition to the agent's own local model. Basically, it concerns integrating information about partners into its planning behavior. Collaboration between planning partners through anticipation has been studied in hierarchical relation types to improve decision making (Schneeweiss & Zimmer, 2004). Anticipation in supply chain planning can be interesting in situations where communication is limited or time is constrained. For example, a drying agent can use an internal model of its partner, the finishing agent, to supply it with alternative products, if the required ones are not available in time.

Negotiation behaviors involve some forms of exchange with partners during planning. This may take the form of proposal and counter proposal (e.g. Contract Net, alternative demand and supply plans). For instance, when the agent is not able to respond to its partner's needs, it can offer changes in delivery dates or alternative products. Following this, an iterative exchange of proposals is started, where both agents try to find a compromise. These proposals can take the shape of new constraints, which can be used by partners to re-plan production and send a new demand plan.

When the agent planning phase is ended, the next phase is the execution of the task flow, which is mainly the allocation of resources (machine, labor, etc.) to specific production tasks. Using a pre-determined algorithm, a production plan is built, creating demand plans for suppliers and supply plans for clients. The last phase is the *Plan diffusion* which distributes operation plans to all interested actors in the environment, including other planning agents and production staff related to the agent.

4.1.3 Industrial base case

In order to use the agent-based planning platform and experiment multi-behavior agents, it was necessary to set an industrial base case. Inspired by a real lumber supply chain, decisions were made concerning the number of partners, production centers, capacity, initial inventory, number of products and demand orders. The production planning agents (sawing, drying and finishing) have been parameterized following realistic industrial production centers in term of production lines, production hours and production processes specific to the lumber industry (e.g. cutting patterns). A total of 45 different products are available to the final client, corresponding to different lengths and quality of wood pieces. An initial inventory has been determined for each production center, corresponding to approximately one week of production at full capacity.

Demand orders from clients are generated by a probabilistic demand generator. This generator creates random demand, according to predetermined settings such as distribution curves, minimum/maximum limits and seasonality. Supply from the forest is considered unlimited, since all demand from the sawing agent is completely fulfilled.

4.2 Framework application

Following the steps described in section 3, we first identified major disturbances that need to be handled in a planning context. Table 1 previously presented the results of our investigation. To simplify the current application, we focused our efforts by considering a common perturbation, which is a new purchase order from a client. Impacts from this perturbation can vary greatly depending on the environment of the agents.

In this case, we identified two different environmental conditions: (1) demand type (spot or contract) proportion and (2) demand intensity. In demand type, we distinguish a spot demand (one-time order, irregular frequency) with contract demand (regular demand from a contract client, including a premium bonus). A late spot demand is considered lost because the client usually changes supplier. A late contract demand is not lost, but a penalty for each day is charged. The demand intensity represents the percentage of production capacity used. For a nominal demand intensity of 100%, which approximately represents the production unit capacity, different intensity can be considered, such as 50% and 150%. Other environmental conditions can be used (but have not been applied here) such as order intensity over total demand and client priority. Order intensity denotes the importance of the last order over all orders. For example, an order can represent less than 1% of the next month's production, which can have a minor impact on production planning. Finally, client priority represents the importance given to a specific client over another, which can give clues about which order to prioritize and which can be late.

In order to respond to this perturbation, different planning behaviors have been identified. Two planning algorithms were used, which are the Just-in-Time (JIT) algorithm and the forward planning algorithm. JIT is about planning orders at the latest possible date without being late, while forward planning plans order as soon as possible. Different planning options related to these two algorithms were available to give different solution: priority on spot orders, priority on contract orders, equal priority for spot and contract, strong penalty for back orders (BO) and equal penalty for inventory and BO. Table 2 presents the different planning options identified in this application. An agent must choose an algorithm, a priority option and a penalty option, creating a specific planning logic.

Planning logic		
Algorithms	**Priority options**	**Penalty options**
Just-In-Time (JIT) Forward planning	Priority on contract Priority on spot Equal priority	Penalty on back orders (BO) Equal penalty inventory/BO

Table 2. Planning logic available to agents

Another way to change supply chain behavior is to modify the coordination strategy between agents. Here, five coordination strategies are identified: downstream planning, upstream planning, two-phase planning, complete planning loop and truncated planning loop. Downstream planning (1) is characterized by plan coordination from the bottom of the supply chain, which is generally used in the lumber industry. In this case, the products harvested in the forest dictate what will be processed in the supply chain. In upstream planning (2), agents plan their operations one after the other, beginning with the agent that is closest to the final customer. This presupposes that each agent is able to satisfy the demand of its customer agent. This mechanism was not used in the present application, mainly because of the difficulty to have good results in a highly dynamic environment such as the lumber industry. Two-phase planning (3) is a coordination mechanism combining both upstream and downstream planning. This approach involves a hierarchy of subproblems that implicates each agent twice (except the raw material supplier). The agent

first makes a temporary plan to compute its supply needs and sends this information to its supplier. In turn, the supplier tries to satisfy this demand and responds with a supply plan that does not necessarily meet all demand (e.g., some deliveries may be planned to be late or some products can be replaced by substitutes). If some capacity is left unused, agents can decide to plan other products by using on-hand inventory. When informed of the supply granted by its supplier, the initial agent has to revise its production plan in order to account for supply constraints.
Also, coordination between partners can be modified by intervening in the sequence of information exchanges. The complete planning loop (4) is referred to as an exchange of plans involving each partner successively, receiving demand plans from immediate customers and transmitting requirement plans to suppliers. The truncated planning loop (5) is similar to the complete loop but skips one or several partners in the communication sequence. This is particularly interesting when a specific production center represents a bottleneck and needs to be planned before other production centers. In this application, the drying unit is an important bottle neck in the supply chain. Figure 4 presents these different coordination strategies.

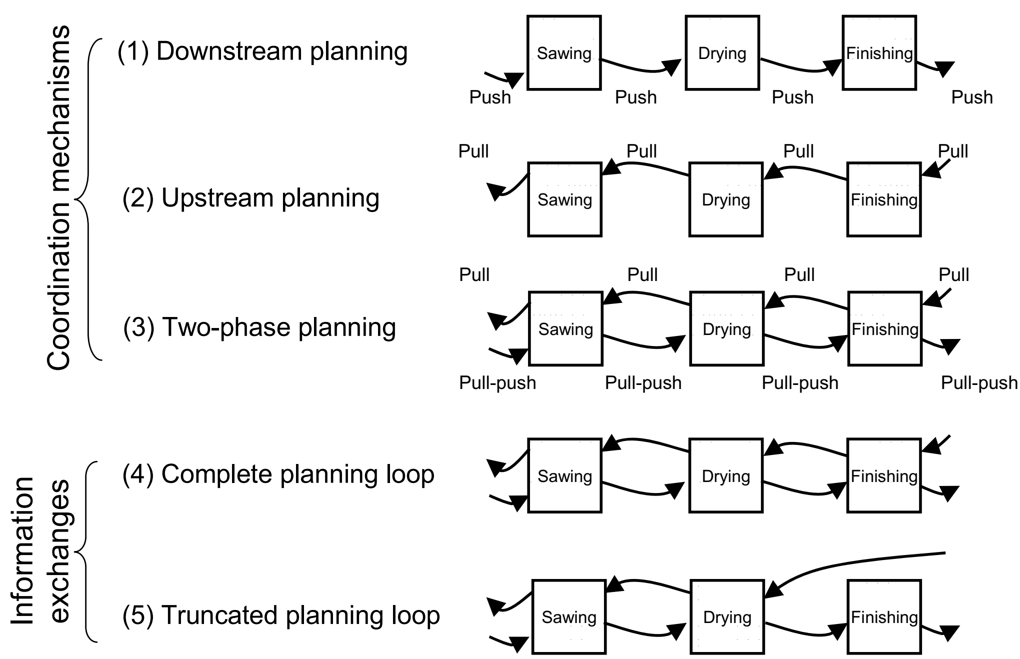

Figure. 4. Coordination strategies and information exchanges

During the team experiments phase, we identified five different planning behavior combinations, leading to five team behaviors. The priority option was applied to the deliver agent only, which had the possibility to put planning priority on different kinds of demand (contract or spot). Coordination mechanisms and information exchange changes were applied to the entire supply chain. This selection of team behavior was based on the experience of managers and researchers, but may not represent the best behaviors available. Table 3 present the team behaviors used in our experiments, which were set for demonstration purposes.

To analyze the different planning behaviors over the supply chain, different performance indicators are used. These can be various, such as maximizing supply chain profit, minimizing inventory and maximizing level of service. Depending on the choice of a specific indicator, the best team behavior may be different. In certain environmental situations, a specific behavior can dominate others for all indicators, but in another situation the same behavior can show poor results. Here, results were analyzed regarding two different performance indicators, which are supply chain inventory and back orders.

	Planning logic			Coordination strategies	
#	**Algorithms**	**Priority options**	**Penalty options**	**Coordination mechanisms**	**Information exchange**
1	JIT	Contract	Back orders	Two-phase	Complete loop
2	Forward planning	Contract	Back orders	Two-phase	Complete loop
3	JIT	Contract	Back orders	Dowstream	Complete loop
4	JIT	No priority	Back orders	Two-phase	Complete loop
5	JIT	Spot	Back orders	Two-phase	Complete loop

Table 3. Team behaviors used in experiments

Basically, in each experiment planning agents have to prepare a production plan for the 30 next days, knowing the incoming orders in that time horizon. Using each team behavior alternatively, the supply chain was confronted with a combination of demand intensity (100%, 50% and 150%) and contract demand proportion (0%, 25%, 50%, 75% and 100%). A penalty cost is associated with lateness of contract demand (1.5% for backorder per day) and a premium bonus is given for the fulfilled contract demand (5%). A daily inventory holding cost of 0.5% of the market value is charged. From these experiments, different graphics were drawn to observe the evolution of the behaviors' performance with supply chain goals. Figures 4 and 5 present a sample of obtained results, showing the evolution of the performance for the different planning behaviors, under different environmental conditions. Figure 4 illustrates the results in terms of average inventory for the entire supply chain, for 50% demand (left graph) and 150% demand (right graph). For this specific performance indicator, it is not possible to identify a dominant planning behavior. Behavior 5 performs better in a context of 50% demand, while behaviors 1 and 4 seem to perform well for 150% demand. In these results, behavior 3 was removed from the figure because it was offering very poor results.

Figure 5 presents another example, showing the evolution of the average lateness (per board foot) for contract demand, again for 50% demand and 150% demand. This time, behaviors 1 and 2 appear very close to each other as the best behavior to adopt. In the case where lateness is a performance indicator, either behavior would be an acceptable choice. But if both minimizing lateness and minimizing inventory are indicators of equal importance (when multiple indicators are used), a different decision can emerge by analyzing results from figure 4 and figure 5. One would prefer behavior 1 as behavior 2 demonstrates poor performance in regard to inventory level. Table 4 presents the best planning behavior for the selected combination of environmental conditions and performance indicators. When two behaviors are suggested, none of these has proven to be significantly better.

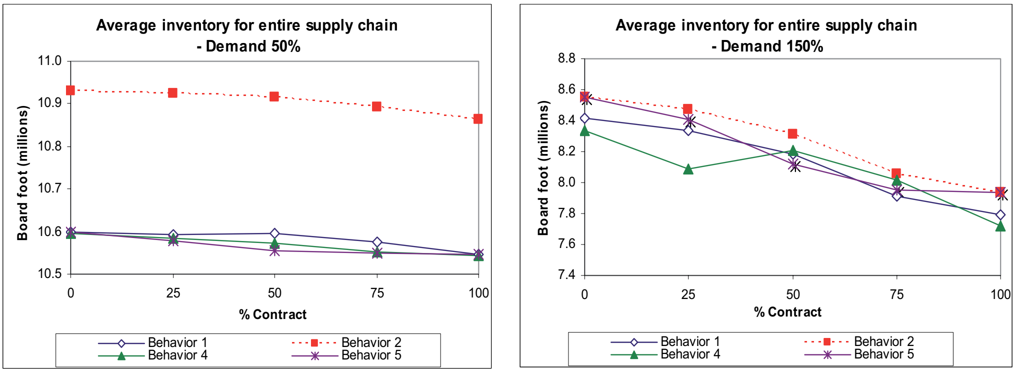

Figure 4. Average inventory for four planning behaviors

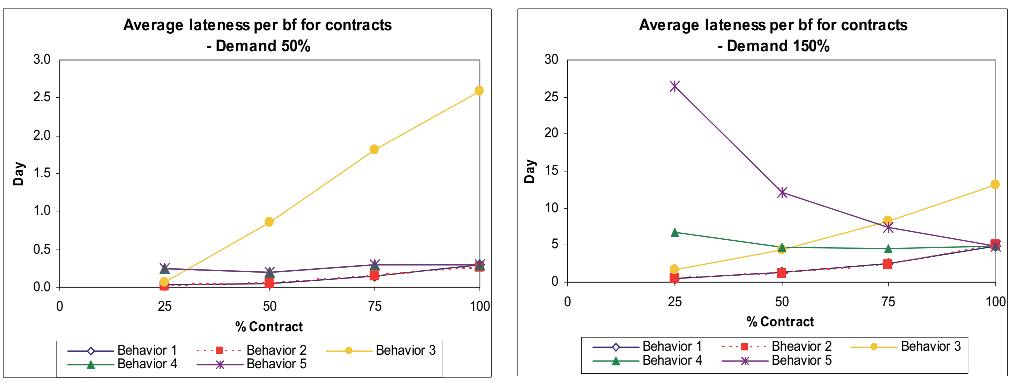

Figure 5. Average lateness for five planning behaviors

Environment \ Objectives		Maximize supply chain profit	Minimize inventory	Minimize BO	Maximize sum of local profits
Demand 50%	Contract <=25%	5	5	1-2	1
	25%< Contract >=75%	5	4	1-2	1
	Contract >75%	5	5	2	1
Demand 100%	Contract <=25%	2	4	1-2	2
	25%< Contract >=75%	2	5	2	2
	Contract >75%	2	5	1	2
Demand 150%	Contract <=25%	5	4	1-2	4
	25%< Contract >=75%	5	1	1-2	4
	Contract >75%	1-5	5	1	4

Table 4. Knowledge matrix built from experiments

Work is still on-going to realize test simulations over a rolling horizon. Figure 6 gives an example of a simulation for a planning agent confronted to perturbations, here with three successive demand intensities. The best team behavior identified from experiments is used with each perturbation. In this example, behavior 1 is associated to 50% demand, behavior 2 with 100% demand and behavior 4 with 150% demand. Results are then compared to a simulation where only one behavior is used instead of different.

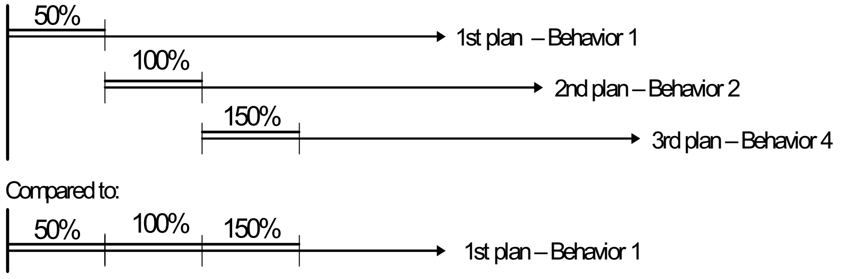

Figure 6. Example of a simulation for a demand increase

5. Conclusion and future work

This chapter proposes a framework to design multi-behavior agents in a supply chain agent-based planning system. The basic steps are described to give a design framework, including (1) the identification of environment characteristics which require a change of behavior, (2) the description of the different planning behaviors available to the agent, (3) an experiment methodology, (4) a test simulation phase and (5) an on-line implementation with continuous learning. An application from the lumber industry has been tested on an agent-based planning platform and results are presented.

By following this design framework for multi-behavior agents, the planning system designer gives a system's agents the possibility to change their planning behavior according to change in the environment, instead of planning with the same strategy over time. Preliminary results show a potential to increase supply chain performance, depending on an agent's local and global goals. Supply chain planning agent models which use the advantage of reactivity, utility evaluation, anticipation and negotiation, such as multi-behavior agents, can be a powerful tool to reach appreciated gains when implemented in an agent-based supply chain planning system such as the FOR@C experimental platform.

Future work is intended to continue this research, starting with the completion of current simulations, the implementation of multi-behavior agents for on-line planning and the development of the on-line learning ability. Several features have been simplified in the application of the design framework presented in this chapter. Experiments were conducted using only reaction behaviors, with a unique perturbation (new demand order). Also, the base case used in this application included a single planning unit. The next application will be extended to multiple planning units, leading to a more complex but realistic supply chain. It will be interesting to develop anticipation and negotiation behaviors, and simulate to compare them to previous behaviors. Another important feature that must be studied is the synchronization of the behaviors of all agents. Indeed, multi-behavior agents can recognize situations and adapt their behavior, but in order to avoid multiple behavior changes, it may be necessary to use a synchronization agent.

6. Acknowledgement

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Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization. An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money. From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle. The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

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